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A MATRIX EVALUATION OF REMOTE SENSOR CAPABILITIES FOR MILITARY GEOGRAPHIC INFORMATION (MGI)

by
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July 1972

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U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
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13. ABSTRACT

This work is an initial attempt to evaluate 20 selected remote sensor types for their ability to obtain data on specific natural and cultural terrain components (81 selected MGI elements). The evaluations were made at three levels according to the complexity of the MGI element and the level of experience required from the interpreter. The MGI elements were categorized into four major divisions. (1) Drainage and Water, (2) Vegetation, (3) Landforms and Surficial Materials, and (4) Cultural and Industrial-Economics. The problems associated with detection of each MGI element, recommended interpretation techniques, and the references pertinent to each evaluation are presented.

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Distributed by

The Commanding Officer
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I-C

SUMMARY

This work is an initial attempt to evaluate 20 selected remote sensor types for their ability to obtain data about specific natural and cultural terrain components (81 selected MGI elements). The evaluations were made at three levels according to the complexity of the MGI element and the level of experience required from the interpreter. The MGI elements were categorized into four major divisions: (1) Drainage and Water, (2) Vegetation, (3) Landforms and Surficial Materials, and (4) Cultural and Industrial-Economics. The problems associated with detection of each MGI element, recommended interpretation techniques, and the references pertinent to each evaluation are presented.

FOREWORD

1. Authority:

This report presents a first iteration of a systematic analysis of sensor capabilities to acquire data base information. The work was performed by the Photo Interpretation Research Division (PIRD), formerly of the U. S. Army Cold Regions Research and Engineering Laboratory in support of the USAETL Military Geographic Information Program under an intra-Army order for reimbursable services. Authority and guidance for establishment of this Work Unit is the letter of 11 July 1968 (Dr. K. R. Kothe, Chief, Geographic Sciences Division, USAETL, to Mr. R. E. Frost, Chief, Photo Interpretation Research Division (PIRD), USACRREL) subject, "Terrain Data Requirements - Sensor Capabilities Matrices," and a subsequent letter dated 26 February 1969 (Mr. R. E. Frost to Dr. K. R. Kothe) subject, "A Matrix Evaluation of Remote Sensor Capabilities for Military Geographic Information." With the subsequent transfer of PIRD to USAETL on 1 September 1970, the work was completed in-house by that element.

2. Results:

An Interim Report, dated December 1969, was submitted outlining the methods and procedures of this study. This final report expands the initial report and presents the results of the evaluation of remote sensor imagery (R.S.I.) for military geographic information.

This report is considered to fulfill the initial requirement. Subsequent testing of sensors and sensor output to establish their ability to produce the required data-base elements of information will lead to improved iterations of the matrix in essentially the same format. The results of this first effort, therefore, are a basis for elaboration and clarification as experimental evidence accumulates from the controlled tests and analyses which will proceed under other work units.

The reader should be aware that a conscious policy has been followed in deciding matrix content; i.e., the more inclusive claim of capability has been accepted in all marginal cases where a clear-cut decision was not evident. This strategy, it is anticipated, will evoke reader response which is eagerly sought to improve the matrix with constructive criticism.

3. Format:

The reader should not proceed to examine the matrices directly because they will seem misleading and complex without prior knowledge of the symbology, methodology, and rationale for their construction and, especially, the basis for the decisions and the reservations which accompany them. The matrices can be read simultaneously with each data element explanation. The bibliographic references are keyed to permit association with particular decisions. An orderly reading as suggested will lead to faster comprehension.

4. Acknowledgments:

The final report is the result of a joint effort by several people. A. Lind (presently with the University of Vermont) and T. Vogel designed the original Matrix format and the numerical scheme used in the evaluations. Lind was also responsible for the section on cultural elements. T. Vogel compiled the section on vegetation, M. Lynch the section on landforms and surficial materials, and R. Birnie (presently in graduate school, Harvard University) was initially responsible for the section on hydrologic elements. This last section was subsequently revised by Lynch.

The authors would like to express their appreciation to Marvin Gast, Chief of the Geographic Application Branch of the Geographic Sciences Division who supplied the listing of MGI elements and Donald Orr of the Technology Development Branch who acted as study monitor.

The authors would also like to acknowledge the other members of the PIRD for their helpful suggestions and discussion, in particular Dr. Jack Rinker, Robert Leighty, and Ambrose Poulin. Interaction in the final stages with personnel of the sponsoring Geographic Information Systems Division helped greatly to sharpen the presentation.

The work for this report was performed under the general supervision of R. E. Frost (Chief), Photographic Interpretation Research Division.

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TABLES

A MATRIX EVALUATION OF REMOTE SENSOR CAPABILITIES FOR MILITARY GEOGRAPHIC INFORMATION (MGI)

I. INTRODUCTION

1. Purpose. This report provides a more quantitative method of evaluating the capabilities of remote sensors with respect to a selected list of Military Geographic Information (MGI)[1] elements at two levels of image interpreter training and experience (essentially novice versus experienced interpreter). This study is in support of advanced sensor configuration and performance requirements.

2. Scope. The evaluations are based on the U. S. Army MGI requirements—as developed in an experimental data base by USAETL Geographic Information Systems Division. The primary source of information necessary for evaluation of the sensor/MGI capabilities selected for this study was scientific and industrial literature. Actual comparative analysis and evaluations of remote sensor test imagery and data were precluded from this initial phase of the study because of the difficulty and time involved in collecting representative samples for each remote sensor. The information gained from review of the literature was tempered with the experience and background of project personnel before each evaluation was made. In general, an objective or quantitative technique for evaluation of remote sensor systems does not now exist.

In cases of doubt, the more inclusive claim for a sensor capability was made in order to evoke reader interaction. This does not entail lavish claims based, for example, on one cited case but does include marginal but credible claims which could not be resolved. Both experimentation and reader interaction will be depended on to achieve a refined iteration at a later date. A controlled photographic imagery analysis program is already under way to provide the future improved data.

II. PROCEDURE

3. Military Geographic Information Elements. This study is largely an attempt to provide the initial working method for a continuing program in support of the MGI data base and data bank program currently under development by USAETL. The present list as recently formulated by USAETL numbers well over 5,000 elements. Approximately 2 percent of these elements are considered here.

[1] MGI is defined as those geographical factors, both cultural and natural that affect a military situation.

Various classification schemes may be applicable to the wide variety of natural and man-made features of the terrain. In this study, four major categories of data elements are identified and coded as follows: (1) Drainage and Hydrology Data (100 Series); (2) Vegetation Data (200 Series); (3) Landforms and Surficial Materials Data (300 Series); and (4) Cultural and Industrial-Economic Data (400 Series). While further division may be made, depending on the specialty preferences involved or the nature of specific problem areas, the fourfold division used here does not differ greatly from accepted topographic data concepts already in use by the U. S. Army. Overlap between certain major categories of topographic information seems inevitable; however, it is not the categorization or classification of the data that is to be stressed but rather the discrete data elements themselves which are of prime importance. While the titles of the above major categories are self-explanatory, some clarification is in order to indicate areas of overlap.

a. Drainage and Hydrology Elements (100). Included in this category are the characteristics of water bodies, such as streams and lakes, and those topographic elements which are intimately associated with these features. Thus, river banks and shorelines are considered here rather than under surficial materials and landforms. A few man-made (cultural) features, such as reservoirs, canals, and drainage ditches, are also considered under this category.

b. Vegetation Elements (200). All vegetative components are included in this category whether they are composed of man-made or natural elements. Although crops are of cultural and economic importance, they are also vegetation or botanical elements from the image interpreter's viewpoint, and the methods of deriving crop information from imagery are similar to those for natural botanical elements with the possible exception of image scale.

c. Landforms and Surficial Materials Elements (300). Bedrock, overburden, and landform elements are grouped under this heading because they are closely related and, from an image interpreter's standpoint, virtually inseparable.

d. Cultural and Industrial-Economic Elements (400). This category includes those man-made features of the terrain that result from human occupancy not covered in the other categories. Included are such diverse elements as roads, railroads, buildings, industries, and land use.

4. Remote Sensors. The selected list of airborne remote sensing systems and portions of the electromagnetic spectrum considered in this study are presented in Table I. In searching for a method to divide the electromagnetic spectrum into workable units, it became evident that two avenues of approach were open. (1) dividing the spectrum into general units, i.e., radar, microwave, etc.; or (2) listing individual sensors, i.e., APQ57,

Table I. Selected Airborne Remote Sensing System Types

Sensing System Type				
I Photographic*	II Electromagnetic-Optical Imaging	III Microwave and Radar	IV Electromagnetic Non-Imaging	V Other Mixed
A Ultraviolet B Panchromatic (B&W) C Color D Color Infrared (false color) E Panchromatic Infrared F Multiband G Narrow Band				
	H Television-type I Multiband Scanners J Infrared Scanners (near, middle, far)			
		K Microwave L Real Aperture Radars M Synthetic Aperture Radars		
			N Gamma Ray O Radiometric-Spectrometric (UV, IR) P Lasers (UV, Visible, IR)	
				Q Magnetometric R Gravimetric S Specialized Electromagnetic (e.g., Magneto-telluric) T Penetrometer

*Vertical, oblique frame, strip, and panoramic imagery are considered under photographic systems B through E.

K-17, etc. Both of these methods have severe limitations – the first because of the general disagreement on limits and the overlap that exists in the major divisions of the electromagnetic spectrum, and the second because it would produce an exceedingly long list of remote sensor hardware. The list finally adopted for this study considers 20 major sensing systems (designated by capital letters in the matrices) and probably should be considered a combination of the above. These major systems represent a large number of individual remote sensors. As an example, a 25A filter used in conjunction with panchromatic film would be evaluated under the "Panchromatic photography" category (B, Table I) and referenced under the pertinent MGI/sensor evaluation.

It is assumed in this study that all remote sensor imagery and data is of the highest quality obtained at recommended exposures, gain settings, etc. For instance, vertical photography would have been obtained with less than 3 degrees of tilt. It is also assumed that for those MGI elements requiring photogrammetric measurements both vertical and horizontal ground control is available, and imagery rectification is possible.

These matrices emphasize the present major sources of MGI, i.e., panchromatic and color photography. It is of importance to note that this emphasis should not detract from the importance of the other sensors but, rather, reflects the long history and development of aerial photography as a tool for gathering terrain information.

5. **Image Interpreter Capability.** The list of remote sensors (Table I) should be considered as remote sensor systems rather than individual pieces of hardware or portions of the electromagnetic spectrum. The aircraft pilot, photographer, darkroom technician, and the image interpreter are also part of the system, and, if any one of these should fail, then, of course, the entire system fails. This study attempts to evaluate two components. (1) the image interpreter, and (2) the remote sensor. The remaining components, while important and which should also be evaluated, are not considered to be within the scope of this study.

The ability of the interpreter to determine individual MGI data elements has been divided into two levels. (a) the interpreter who has basic knowledge, as provided by military image interpretation schools, but who does not have extensive experience or training in the terrain and engineering sciences concerned with MGI, and (b) the experienced interpreter who has the complete breadth of required technical knowledge both in the terrain and engineering sciences and in image interpretation skills. In the body of the matrix, these levels are coded as:

0 = probable failure at both levels of interpreter experience (extensive ground data collection or supplementary sensor imagery or data is generally required at the present state-of-the-art).

1 = success probable at higher experience level only.

2 = success probable at both experience levels (success at this lower level cannot occur without success at the higher level also).

X = remote sensor–MGI element combination mutually exclusive or incompatible.

Selection of an appropriate entry in the evaluation code (0,1,2,X) was based on the experience of the authors' capabilities, the literature they reviewed, and the comments of colleagues.

These evaluation codes signify that, generally, in the authors' opinion, the indicated level of interpreter experience is the minimum needed to extract the MGI element from the imagery. The modifying statement "generally" is important because in any entry there will be exceptions, and there will be instances where a supposedly difficult MGI requirement can be accomplished by a less experienced interpreter; for example, extensive use of image interpretation key maps or other information for a particular MGI element by a technician-level interpreter (code 2). In all entries where success is indicated on both high and low levels of interpreter experience (code 2), it is assumed that the MGI element is well defined and easily identifiable. In those instances where only obscure traces or other subtle and indirect evidence exist, the services of a skilled interpreter are required (code 1).

The entry "0" is construed to mean that at the present state-of-the-art extensive ground data or supplementary or complex inferred information is required to obtain data on this particular MGI element.

The "X" entry is defined as an incompatibility of the remote sensor- MGI element selection. As examples, a gravimeter could not be utilized to determine soil or vegetation color nor would a laser profiler be employed to determine the area of a forest clearing.

Other than the mutually exclusive entries (code X), no allowance has been made for the appropriateness of each sensor-element match. Entries have been made wherever it is at least theoretically possible to derive useful data, although it is recognized that the particular sensor may not be practically used for that particular purpose. It is assumed that this matrix will enable rational determinations of sensor selection and expected interpreter performance.

6. **Sensor Ranking.** An attempt was made to select the three most generally useful sensors for obtaining information on each particular MGI element. A code (A,B,C) was used to indicate the selected sensors and to rank them ("A" indicates first choice). Criteria used in making the selection were the inherent information content of the sensor imagery and the ease of detection and interpretation. In some instances, an identical double entry was made where it was difficult to decide which sensor was most suitable. Two sensors, for instance, might both be given "C" ratings (third-choice rating).

It was assumed that these sensors would be operated under optimum, daylight conditions. Such an assumption necessarily puts bias into the selection and does not give due consideration to such sensors as radar which can operate at night or can image through cloud cover. A more complex code which could more realistically accommodate the broad spectrum of remote sensors and include environmental considerations could be formulated in the future.

7. **Matrix Format.** The MGI elements presented in the matrices are numbered in such a manner that the number identifies the category to which the element belongs. For example, 101 is the first data element under the Drainage and Water category; 201 would be the first data element under the Vegetation category. As more elements are added, the element numbers can be increased to four digits, thus allowing for an open-ended MGI element list. The elements are presented along the left margin of the matrix with the sensor systems forming the top of the matrix as columns (Tables II through V). (The tables are located at the end of paras. 9, 10, 11, and 12.) The evaluations of the sensor systems and sensor ranking for each MGI element are located at the intersections of the rows and columns. As may be expected in a study of this type, numerous explanatory notes are necessary to provide the limitations and auxiliary information for each MGI element sensor evaluation.

8. **Explanatory Notes.** Paragraphs 9 through 12 provide the reader with the details and problems associated with the detection, identification, interpretation, or measurement of each MGI element. Each element is defined. The interpretation methods are discussed, and recommendations are presented for the most suitable remote sensor. The references and bibliography for the evaluations can be found at the end of each of the four categories and are keyed to each MGI element by their matrix number.

9. Explanatory Notes for Hydrologic Elements (100 Series).

a. Evaluation of the 100 Series.

101. DEPTH OF WATER BODY

(a) Definition: A determination of the vertical distance from the water-air interface to the water-bottom interface.

(b) Interpretation Variables: Because of the nature of water, most proven techniques for remotely determining water depths have been restricted to the photographic systems. There are three main photographic techniques for determining water depths (Sonu, 1964):

(1) Penetration Method: Imaging of bottom of water body; light energy has penetrated water and has been reflected from bottom surface.

(2) Wave Method: Analysis of the shoaling characteristics of waves approaching shore; depth is inferred from wave transformation behavior.

(3) Transparency Method: Analysis of tones on photographic imagery; depth of water is indicated by extinction values of light emerging from the water as portrayed in photographic tonal differences.

Photographic penetration techniques have proven to be the most useful and accurate. Depths of penetration and imaging of bottom detail as reported in the literature have ranged from a few feet to about 150 feet; the greatest depths tend to be in tropical ocean water. Imaging of bottom surfaces depends on the contrast of the bottom as well as penetration of light.

Photographic techniques (other techniques also) for water-depth determinations are complicated by the fact that, in addition to problems of light transmission through the atmosphere, there are the problems of light transmission through a water medium. Water quality is the main factor controlling the depth of penetration of light. A good discussion of the basis of this problem is presented in the *Manual of Photographic Interpretation* (1960), Chapter Two, Appendix C: "The Procurement of Aerial Photography of Underwater Objects—An Analysis of the Problem by Russian Scientists."

(c) Remote Sensor Applications: Water depths can be determined by using a variety of photographic emulsions that record reflected light from bottom surfaces of water bodies. Color films appear to be the most widely used for depth determinations (Geary, 1968; Vary, 1969; Schneider, 1968; Swanson, 1960, 1964) Techniques

range from estimates to photogrammetric methods. Depth determinations from stereo methods have had accuracies of ±.5 foot to depths of 10 feet; this accuracy was valid for altitudes between 1,000 and 10,000 feet (Conrad, *et al.,* 1968).

A method of depth determination using a stereo plotter and vertical panchromatic photography was initially described by Tewinkel (1963). This method as modified by van Wijk has achieved an accuracy of ±4% for moderate depths. Joering (1969) has also used panchromatic vertical airphotos at a scale of 1/6400 to estimate stream depths with good results.

Multispectral camera techniques should have good potential for water-depth determinations since it is possible to select those wavelength bands of light most transparent to the type of water being investigated. Maximum and minimum values of absorption and scattering for various wavelengths of light differ greatly between river, lake, and ocean water. A number of articles give the depths recorded with various film/filter combinations on various types of water. (Some of these articles are listed as references at the end of this presentation.)

Laser ranging sensors have been used to measure depths directly to 150 feet from an altitude of 1,500 feet (Polcyn and Sattinger, 1969). Air-droppable penetrometers may also be able to provide point data on water depth.

Estimates of water depth are also possible from Apollo and Gemini type imagery (Geary, 1968).

Depths of small mountain lakes have been determined rather accurately by a technique based on measurement of shore slopes from photography (Moessner, 1963). It may also be possible to apply similar techniques to some rivers and streams. Determinations of the depth of small lakes, streams, and rivers can also be aided by a number of natural and artificial features that give clues to the water depth, some of these features are boulders, rapids, and riffles, tree stumps in flooded areas, types of aquatic vegetation; buoys; fords; and various longshore cultural features.

Depth changes can also be inferred using a standard hydraulic velocity and flow formula if velocity changes across a stream cross section can be determined.

102. VELOCITY OF WATER FLOW

(a) Definition: A determination of the rate at which surface water is flowing in a stream or other water body.

(b) Interpretation Variables: Various techniques have been employed for determining the rate of surface-water movement in streams, rivers, lakes, and oceans. These techniques have ranged from simple estimates of flow velocity to complex photogrammetric procedures. One common problem is locating reference points on the water surface. Various natural features and artificial targets have been employed as reference points including waves, eddies, lines of foam, zones of discolored water, floating ice, floating logs, and steel drums.

Among the methods used for flow-velocity determinations, techniques utilizing photography have been the most common. A variety of cameras, lenses, films, and image scales have been employed. In general, larger scale imagery is needed for making flow velocity determinations on streams and rivers than on large lakes and ocean areas. Very small scale photography has been used successfully for determining velocities of ocean and tidal currents, and TIROS-type imagery has been used for monitoring movements of large ice packs.

(c) Remote Sensor Applications: By measuring the movement of converging lines of foam, discolored water, and floating targets with timed, sequential panchromatic photographs (scale 1:80,000), Keller (1963) determined tidal current velocities within a ±2-knot accuracy. Other studies using floating targets have been described by Duxbury (1967) and Oros (1952) for the Columbia River.

Photographic parallax methods have been applied to the determination of current velocities in streams, rivers, lakes, and oceans. Forrester and Cross (1960) have used panchromatic photographs taken at altitudes between 3,000 and 6,000 feet to obtain photogrammetric measurements of stream flow that are within 10% of the values obtained with standard stream gauges.

Cameron (1962) states that with scales ranging from 1:6,000 to 1:60,000 it has been possible to determine water velocities ranging from 0.25 to 14 miles per hour. He also states that the main factors limiting velocity determinations are the amount of water displacement during the time interval between successive photo frames and the photo scale. A wide latitude of water-velocity differences, however, can be accommodated when obtaining aerial photography by varying aircraft speed, photo scale, and time between photo frames. For very low current velocities, it may even be necessary to make a successive run. Cameron (1962) also gives details for recognizing and correcting for anomalous surface-water movements caused by wind.

Estimates of surface-water velocity have been made based on observation of wave patterns on low level photographs (Poleyn and Sattinger, 1969; Paulson, 1968). Krudristskii, *et al.* (1956), has estimated stream-flow velocities from aerial photographs (1:3,000 scale) by analyzing the wakes produced by obstructions. Joering (1969) used

panchromatic photographs at a scale of 1.6400 to estimate stream-flow velocities. Obstruction wakes and other wave turbulence effects have been observed on radars of both poor and excellent resolution.

Radar returns from artificial reflectors have been used to measure ocean-current velocities (Nikiten, 1957). Similar techniques may also work with natural floating reflectors such as ice floes. Low velocities are detectable with Moving Target Indicator (MTI) radars.

Radioactive tracers have been added to water and monitored with gamma-ray spectrometers to determine velocities (Zoitzeff and Sherman, 1968). In a similar manner, chemical dyes have been used in conjunction with sequential photography.

Observations on the rate and magnitude of movement of ice packs have been made on Apollo type imagery (Cameron, 1962).

103. BANK/SHORE LOCATION

(a) Definition: A determination of the position of the air/water/land interface.

(b) Interpretation Variables: To determine the location of the bank or shore and water interface remotely, a sensor must be able to discriminate between the water and the land surface. This is generally possible since water and land differ in characteristics of reflectivity, thermal properties, and topographic expression. Boundary determinations are usually easier to locate where there is some sharp topographic break at the land/water interface. This boundary can be obscured by aquatic and land vegetation especially in streams and ponds. (See also category 108, "Area of Flooding.")

(c) Remote Sensor Applications: Aerial photography has been widely used for location of bank and shore boundaries. Vertical photographs are most commonly used, but other formats such as oblique are also useful. Scales vary with size of water body, nature of land/water interface, type of film, and accuracy requirements; but, generally, larger scales are needed for accurate boundary determinations on streams and ponds than on larger water bodies. Stereo coverage is generally necessary for high accuracy. General drainage maps can be made from aerial photography of very small scale.

For drainage mapping at a 1/20,000 scal which includes tertiary-order streams, Anson (1966) has shown that detection ability increases from panchromatic to color to Ektachrome Infrared photographic emulsions. Infrared film is superior to normal photographic emulsions because of the high reflectivity of vegetation and high absorptance of water in the near-infrared wavelengths. Land/water contrast is enhanced and vegetation areas are highlighted. The usefulness of infrared emulsions for drainage

studies has been extensively documented (Colwell, 1966; Jones, 1957; Lohman and Robinove, 1964; Marshall, 1968; McBeth, 1956; Robinove, 1968; Ross, 1969; Schneider, 1968; Swanson, 1960, 1964). These studies also show that color IR permits tracing of the drainage closer to its source.

Black and white vertical airphotos at a scale of 1:24,000 have been used successfully to locate drainage ditches (Sternberg, 1961). Imagery from a multiband camera system (nine lens) at a scale of 1:20,000 has been used to locate ponds and rivers and their bank boundaries (Molineux, 1965). Some work has been done with waveform analysis of multisensor imagery whereby drainage channels are automatically located according to gray-tone signatures (Latham and Witmer, 1967).

Thermal infrared and passive microwave imagery can be used to locate land/water boundaries. Differences in thermal properties of water and materials making up the land surface provide the basis for discrimination. Spatial resolution of the imagery, however, is poorer than photography especially for passive microwave imagery.

Radar imagery, especially side-looking airborne radar (SLAR), can be used to map drainage on a small-scale, wide area basis. Drainage channels can be outlined in stark detail depending on the amount of local channel relief, resolution of radar equipment, and orientation of channels with respect to the radar platform. Radar has the capability (real and apparent) of penetrating vegetation to a certain degree and can be used under a variety of atmospheric conditions during the day or night. Water areas will generally show up on radar imagery as "no return" areas because of high specular reflection (for smooth surfaces) of incident radar energy. If the land surface along the edge of a water body exhibits sufficient relief or roughness, especially at the usually shallow angles of incidence, then the interface should be readily detectable. Small-scale and limited resolution, however, affect the overall accuracy of land/water interface determinations.

Radar imagery is especially useful for boundary mapping of large water bodies. Very small water bodies, however, may go undetected. In a general study, Simpson (1969) reported that ponds on the order of 200 yards in diameter were on the threshold of detectability on the radar imagery examined (15 mile-wide strip imagery APQ-97, K band).

Laser terrain profilers have the potential to accurately determine water/land boundaries on the basis of relief and surface roughness. The laser provides only a narrow trace, however, and does not have the broad area coverage that imagery provides. There also can be problems with determining the exact geographic location of the laser trace, and anomalous return signals can be generated. Link (1969) reported that a laser profiler (operating at 6328Å) flown at an altitude of 500 feet at a speed of

250 feet/second had a vertical resolution of 0.3 foot and a horizontal resolution of 1.7 feet. The laser can be effective, however, if flown with a boresight camera with sufficient care.

104. BANK/SHORE COMPOSITION

(a) Definition: A determination of the composition of the materials comprising the bank or shore of a water body.

(b) Interpretation Variables: Numerous techniques and clues are used to determine the physical and chemical makeup of bank and shore materials. Essentially, these techniques are similar to those used for determining the composition of surface deposits and materials in general. These subjects are discussed more thoroughly under elements 301 (Type of Surficial Deposit) and 302 (Composition of Surficial Deposit). Other pertinent elements are 109 (Stream Bed Composition) and 107 (Bank/Shore Stability).

Of particular importance to the determination of bank/shore composition, other than spectral reflectance characteristics, are evaluations of the shape and features of the bank or shore such as gullies, cuts and vegetation, and the general stability and behavior of bank/shore materials in relation to various active hydro-processes of associated water bodies.

(c) Remote Sensor Applications: Photography, in general, and color and color IR photography, in particular, would probably be the most useful type of remote sensor imagery for determining the composition, major features, and general characteristics of banks and shores.

105. BANK/SHORE SLOPE

(a) Definition: A determination of the slope of a bank or shore surface as referenced to the horizontal.

(b) Interpretation Variables: Bank/shore slope is a special facet of the overall problem of determining the slope of terrain features from remote sensor imagery which is treated under element 314. Because of the generally limited dimensions of most banks and shores, large scale imagery is usually necessary for making the horizontal and vertical measurements required for calculating slopes. Representative sites must be selected and measurements made along a line from the land/water interface to the top of the bank or shore. Vegetation and cultural features can aid or hinder slope determinations. Other elements containing information pertinent to this discussion include 103 (Bank/Shore Location), 107 (Bank/Shore Stability), and 108 (Area of Flooding).

(c) Remote Sensor Applications· Stereo photography, in general, would be the most useful type of remote sensor imagery for determining bank/shore slope. The most useful film type would depend on the nature of the bank/shore; ease of delineating land/water boundaries and other boundaries, and presence of vegetation cultural features, etc. Color and color IR films generally allow greater discrimination between these various features. However, other films, such as black and white IR, which is valuable for delineating land/water boundaries, are useful.

Bank/shore slope measurements of high accuracy can also be made by a laser profiler at selected cross sections. Simulations made at the U.S. Army Waterways Experiment Station (WES) indicate that such laser applications would be effective even through dense canopy (draft of TERRAS report by A. Williamson to B. Scheps (USAETL), 1971).

106. BANK/SHORE HEIGHT

(a) Definition: A determination of the elevation of a bank or shore above the general water level.

(b) Interpretation Variables: The determination of bank/shore height from remote sensor imagery will not be discussed in detail here. The reader is referred to the general discussions on elevation (313) and slope (314). The determination of bank/shore height is a special category of the overall problem of determining elevations of natural features. Since banks and shores are generally not of great magnitude vertically, useful imagery for determining their height must necessarily be of large scale such as 1:3000. Land/water boundaries must also stand out clearly on the imagery. Other categories in this report applicable to the problem of determining bank/shore height include 103 (Bank/Shore Location), 107 (Bank/Shore Stability), and 108 (Area of Flooding).

(c) Remote Sensor Applications: Large-scale stereo photography would generally be the most useful type of remote sensor imagery for determining the height of banks and shores. The photography provides a continuous picture map of the bank or shore, and representative sites can be selected for measurement. The laser profiler can provide highly accurate data on bank/shore height but only at selected points which must be chosen before or during the flight mission. Photography provides a permanent record of the bank/shore and permits leisurely investigation and selective measurement along any part of the imaged bank or shore. Color and color IR films would be generally more advantageous for bank/shore height determinations since greater discrimination is usually possible between land and water, vegetation, bank/shore materials, and cultural features. Other films, however, can also produce good results.

107. BANK/SHORE STABILITY

(a) Definition: A determination of the permanency or resistance to change of a bank or shore to natural erosive agents.

(b) Interpretation Variables: The stability of stream banks and shorelines of water bodies depends on a number of factors including the composition and size distribution of bank/shore materials, height, slope and structure of the bank/shore, presence of stabilizing vegetation, and location and degree of exposure of the bank/shore to strong water currents and waves. Banks and shores composed of resistant materials may be quite stable even when subjected to highly erosive hydro processes. Banks and shores composed of easily erodible materials may also be fairly stable if located in a low-energy area such as along a slow, meandering stream having a small yearly discharge amplitude; a quiet pond; or an estuary backwater. Unstable bank/shore conditions are brought about largely by a combination of factors such as erosion-susceptible materials and exposure to strong currents and wave attack due to storms and floods. Bank/shore failure or deformation such as slumping or landsliding can also occur locally through processes such as earth tremors which are not directly related to water-body erosion.

(c) Remote Sensor Applications: The identification of the type and composition of materials making up the bank/shore is an especially important factor for evaluating stability. These items are treated, generally, under elements 301 and 302 and, specifically, under element 104 (Bank/Shore Composition). Such items as the shape of cuts and gullies aid the interpreter in determining the general nature of bank/shore materials. The presence of slumps and associated features indicative of failure also gives clues as to the degree of bank/shore stability. The presence of man-made, protective features such as jetties and retaining walls can also be used in evaluating bank/shore stability.

One of the best methods of determining bank/shore stability is actual observation over a period of time. Such an empirical technique allows determination of areas of change, rate of change, and volume of material eroded or accreted and makes possible predictions based on observed trends. Both aerial and ground-based sequential photography (including motion pictures) have been widely used for this purpose.

Stafford and Longfelder (1971) report on a coastal study in North Carolina in which sequential aerial photography was used to document change. Measurements were made at select reference points between the dune line and high water line with consideration paid to the time of year of the photography and the representativeness of the prevailing conditions. Rectified enlargements proved very valuable, their use resulted in the smallest composite error of the various types of photography

employed. For a particular type of photography (rectified, unrectified, etc.), the composite error also decreased with increasing scale.

Panchromatic film was used in the above study because it represented the photography generally available from various government agencies. Color and color IR photography would also be useful for similar studies especially for identification of surface materials, associated vegetation, and cultural features. For large area surveys, however, any added benefit from the use of color or color IR films would probably not outweigh the additional cost.

The general literature on the application of aerial and ground photography to coastal studies is reviewed by Stafford (1968).

Remote sensor imagery other than photography can also be useful for appraising general bank and shore conditions, the usefulness depending largely on the scale, resolution, and quality of the particular type of imagery. Pertinent information relating to various types of remote sensor imagery is contained also in element 103 (Bank/Shore Location).

In a study of the Delta River, Alaska (Dingman, *et al.*, 1971), a braided glacial stream, aerial and ground-based sequential photography (panchromatic) were used to document short- and long-term changes in the channels and banks of the river. On such streams, the unconsolidated banks are particularly susceptible to erosion because of large diurnal and seasonal fluctuations in discharge. Rapid shifting and migration of stream channels make the banks susceptible to erosion along any reach. Large scale photography on the order of 1:10,000 or greater is desirable for studying the bank conditions of such streams.

108. AREA OF FLOODING

(a) Definition. A determination of the area covered by an overflow of water onto normally dry land.

(b) Interpretation Variables: The subject area of flooding has several facets which include:

(1) Determining the area inundated during active floods.

(2) Determining the area of recent floods from postflood surveys conducted within a relatively short time after occurrence (for instance, 6 months).

(3) Determining the extent of older, historic floods. This category could be expanded to include ancient floods which properly belong to the field of paleohydrology.

(4) Theoretically determining areas and depths of inundation for given volumes of water. Such calculations must be made for flood-control projects and dams and for general planning purposes.

This review of remote sensing techniques for determining the area of flooding will deal primarily with active floods and will be largely confined to the use of aerial photography. Floods can occur on floodplains of streams and rivers and on lowland areas bordering major water bodies including the ocean. For example, hurricanes have caused extensive flooding of inland areas of the Gulf Coast.

Much of the material presented under element 103 (Bank/Shore Location) is applicable also to the problem of determining area of floods.

For making area determinations, some type of imagery is required. Useful scales depend on the extent of flooding, contrast between flooded area and surroundings, type and quality of imagery, ease of boundary determinations, and accuracy required. The geometry and mensuration quality of various types of remote sensor imagery are discussed under element 303 (Area of Surficial Deposit).

(c) Remote Sensor Application: Burgess (1967, 1971) gives a comprehensive treatment of various photographic techniques for conducting aerial surveys of active floods. Both vertical and oblique photography are useful. Photography should be obtained at crest stage or just prior to crest stage. The recording of floods is sometimes difficult because of the necessity of planning missions on an emergency basis and because of adverse weather conditions commonly accompanying floods. Expedient procedures must sometimes be used.

Large-format press cameras and panchromatic film have been used to obtain satisfactory oblique photographs of floods from low-flying aircraft. Adverse weather conditions can affect the quality of photography and limit the choice of films. Panchromatic films are most commonly used because of their wide exposure latitude. Color and color IR films can yield excellent data on floods if meteorological conditions allow their use. Hunter and Bird (1970) present an excellent discussion on the optimum uses and limiting factors (including meteorological factors) of various types of films.

Burgess (1967, 1971) also outlines procedures for conducting post-flood surveys and reviews the many diverse lines of evidence that can be used to determine

the limits of past floods. Such determinations require much skill on the part of investigators.

Parker, *et al.* (1970), have used panchromatic and color photography to determine the boundaries of the 100-year recurrence interval flood on a stream in southern Wisconsin. The 100-year flood is a widely used index for planning purposes, and its critical parameters are usually determined by engineering surveys. Generally good results were obtained using the photography only, especially in areas where land forms were well defined.

Bauer (1967) gives a general review of floodplain delineation and mapping for planning purposes.

An airborne multispectral television system has been used to obtain imagery of flooded areas (Robinove and Skibitzke, 1967). Small-scale SLAR imagery has been used to map large flood-plain features (Robinove, 1968; McAnerney, 1966).

Thermal IR imagery, as well as radar imagery, would also have value for conducting surveys of active floods. Radar imagery, however, would be more applicable for recording floods of wide areal extent.

109. STREAM BED COMPOSITION

(a) Definition: A determination of the type and makeup of materials comprising the beds of streams or other water bodies.

(b) Interpretation Variables: Stream bed composition can refer to the general physical or chemical makeup of bottom materials. Physical makeup includes the size gradations of bottom materials, expressed in terms such as sand and gravel, and also the general types of rocks and minerals comprising the bottom assemblage. Chemical composition can be inferred from the type identification of bottom materials. This discussion applies not only to streams but also to the determination of bottom materials in other water bodies as well.

The application of remote sensors for determining the type and composition of surficial materials is discussed under the sections on Landforms and Surficial Materials (elements 301, 302). The techniques for determining the composition of both subaerial and subaqueous materials by remote means are essentially similar. In the case of subaqueous materials, however, an intervening water layer of varying depth is present which complicates the use of some sensors and nullifies the use of others.

(c) **Remote Sensor Applications:** Various remote sensors can be used to determine the composition of bottom materials of streams and water bodies. Both direct and indirect techniques are used. Direct techniques involve the actual sensing of bottom materials by water penetration, etc. Indirect techniques consist largely of interpretive judgments made about bottom materials through an analysis of surface bank/shore materials, materials making up the watershed, etc.

The problem of determining water depth by remote means is discussed under element 101. Much of this discussion is applicable to the problem of determining the composition of bottom materials. For streams and water bodies of moderate depth, color photography would generally be the most useful for determining bottom composition. A skilled interpreter is needed to make valid judgments. Such factors as water turbidity, however, limit the depth of penetration and affect the overall utility of photography. Many factors must be considered when plans are made to acquire photography for such purposes as determining depth of water and composition of bottom materials. Some of these necessary considerations are discussed by Lukens (1968).

Much can be learned about the nature of stream-bottom materials by studying the bedrock and surficial materials of the stream watershed. These can give clues to the likely physical and chemical makeup of the stream-bottom materials. In like manner, the materials making up the banks and floodplains of streams can be used as general indicators of the nature of bottom materials (see element 104, Bank/Shore Composition).

On water bodies other than streams, much can also be inferred about the general nature of bottom materials. The bottom sediments of areas offshore from debouching streams and rivers most likely will be similar to the sediments being discharged. The size distribution of the bottom sediments will reflect the sorting action of various nearshore and offshore currents with sediment size generally decreasing outward from the shore.

The identification of ocean-bottom sediments is simplified by the fact that a limited variety of sediments (various muds, carbonates, etc.) comprises a great portion of the bottom sediments of the world's oceans (Hickman, 1969). Thus, the nature of the bottom sediments can be predicted in many instances. The various remote sensors used in oceanographic research, including bottom investigations, are discussed by Zaitzeff and Sherman (1966). Hickman (1969) discusses the use of a pulsed, near-blue-green laser for various hydrologic and oceanographic applications including identification of bottom materials in water of shallow-to moderate depth.

110. STREAM BED GRADIENT

(a) Definition: A determination of the slope or gradient of the stream bed usually expressed in terms such as feet per mile.

(b) Interpretation Variables: The gradient of a stream or segment of a stream can be determined by using the stream bottom or the water surface as the reference plane or, in instances where the slope of the land surface approximates the stream gradient, the land surface can be used as the reference plane. Gradients can be determined for the entire stream on a regional basis or locally for individual reaches.

(c) Remote Sensor Applications: The determination of stream bed gradients or stream gradients in general will not be reviewed in detail here. Discussions pertinent to this subject are presented under other elements in this report, particularly 313 (Landform Elevation), 314 (Landform Slope Angle), 101 (Depth of Water Body), and 109 (Stream Bed Composition).

In general, stereo photography would be most useful for determining stream gradients, color photography or panchromatic with appropriate filters for determining stream-bottom gradients, and panchromatic for determining the gradient of the water surface. Laser profilers would also have some application for determining gradients on specific streams. Radar imagery (SLAR in particular) would have some application for determining regional gradients of streams and also regional gradients of stream watersheds. In all determinations, such as stream gradients, both horizontal and vertical references must be maintained.

111. TYPE OF WATER POLLUTANTS

(a) Definition: A determination of any physical, chemical, or biological component of a water mass that alters its natural ecological balance.

(b) Interpretation Variables: The evidence of water pollution ranges from the apparent and easily detectable to that which is more subtle and difficult to detect. The pollution may range from the esthetically displeasing but harmless litter to effluents which contaminate or severely alter the ecological balance of a water body. Floating foreign material may be very apparent, abrupt changes in turbidity and water color may be noticeable, and even odors may be strong. In other cases, pollution characteristics may not be pronounced and only indirectly detectable.

(c) Remote Sensor Applications: Aerial photography has been widely used for pollution studies. The variety of cameras, films, and filters and excellent resolution and versatility make photography a very useful tool.

UV spectrazonal photography has been used for detecting oil slicks; the oil slick will appear brighter than the surrounding water (Lowe and Hasell, 1966).

Panchromatic and color emulsions would also have some value for detecting oil slicks; differences in spectral response as well as indirect indicators of the presence and extent of an oil slick such as anomalous wave patterns, etc., could probably be recorded.

Sewage pollution has been successfully detected with color and panchromatic (minus blue) photography (Strandberg, 1964). Color photography is useful for detecting many types of water pollution. Minor tonal differences can be important indicators of abnormal conditions in a water body; heated water may even show up as distinct tones on photography. Color emulsions are capable of recording a great range of tones.

Many types of water pollution exhibit distinct colors. Various chemicals and other wastes discharged into a water body can be detected on the basis of color. The color of the water itself may be altered, or the banks and bottom gravels may be stained. The presence of "yellow-boy" stains in the streams of the Appalachian Mountain mining districts indicates areas where sulfuric acid–resulting from the decomposition of iron sulphides–is leaching into the water.

Color and color IR films also allow discrimination of vegetation. Type and vigor of aquatic vegetation can indicate polluted conditions and sources of outflow of effluents. Increased algae growth is a characteristic of enriched water bodies.

Color photography has proven valuable for monitoring sediment in water and for mapping sediment accumulations (Schneider, 1968, Lohman and Robinove, 1964). Increasing sediment in water shifts water color toward the green (Yost and Wenderoth, 1968) and alters tones on IR sensitive films because of increasing reflectivity of IR. Color IR films are especially useful when haze is a problem.

Photography is a useful sensor in itself for pollution studies and is a valuable supplement to other more-exotic sensors.

Multiband sensors have been widely experimented with for pollution detection. Coverage of the expanded, visible spectrum with a variety of film and filter combinations gives a good basis for detection of a variety of pollution types. Such sensors should be especially valuable for reconnaissance work where a variety of pollution problems and sources may be encountered. Multiband sensors should be useful in a general water quality reconnaissance system such as outlined by Strandberg (1964).

Multiband and thermal sensor systems are currently being evaluated for pollution studies by North American Rockwell Corporation.

Thermal IR sensors are widely used for pollution studies. Much of the effluents introduced into water bodies are either warmer or colder than the water body itself, and these can be detected and point sources can be identified. Biodegradeable effluent also gives off heat which may be detectable in the process of decomposing. Thermal sensors have obvious value for locating discharge points of sewage and heated effluent from power plants and for studying the dispersion and diffusion of these effluents. Thermal sensors also have application for studying the natural currents and mixing conditions in estuaries and littoral environments (Stingelin and Fisher, 1967).

Thermal IR imagery has been used successfully to monitor oil pollution (Lowe and Hasell, 1969; Ester and Golomb, 1970). An oil slick may appear warmer or colder than surrounding water depending on thickness of oil, mixing conditions, surface roughness, amount of sunshine, time of day, etc. Under ideal conditions, the varying thermal response of the oil slick may be used to indicate differences in its relative thickness.

Thermal IR radiometers are useful for obtaining quantitative data for pollution studies and for establishing the natural diurnal and seasonal temperature regime of water bodies (Van Lopik, 1968).

Passive microwave radiometers and imagers serve a function similar to thermal IR imagers and radiometers. Pollutants are detected as a function of emissivity-temperature anomalies. Microwave radiometers are used for monitoring water-surface temperatures. Oil slicks have been detected based on thermal differences and change in water-surface roughness associated with an oil-spill area (Aukland, *et al.*, 1969b).

Radar imagery has proven successful for monitoring the extent of oil slicks (Guinard and Purves, 1970). Other sensor systems have also proven useful for detecting and mapping oil slicks. A technique is needed for remotely determining the exact thickness of oil on the water surface.

UV lasers could be used to stimulate luminescence in oil-covered water, and the affected areas could thus be recorded.

Gamma-ray and other radiation detectors would have use for monitoring radioactive contamination of water bodies or for keeping track of introduced radioactive substances for determining flow and dispersion characteristics. The technique is similar to the use of chemical dyes as tracers.

112. FRESHWATER/SALTWATER INTERFACE

(a) Definition: A determination of the general boundary between freshwater and saltwater.

Other elements in this section on Hydrologic Elements have application to the subject of location of freshwater/saltwater interfaces and should also be read (111, 116, 117).

(b) Interpretation Variables: Determinations of freshwater/saltwater boundaries must generally be approximate determinations, because there is probably a transition zone between water which can be definitely considered saline (or brackish) and that which is fresh (definitions of freshwater and saltwater can also vary). Water bodies are also dynamic, and boundaries can fluctuate greatly in time.

Such freshwater/saltwater boundaries exist in areas where rivers and surface and subsurface springs flow into saline water bodies. Detection of these freshwater flows and surface boundaries is made on the basis of a variety of associated surface phenomena such as tonal differences caused by quality and quantity of dissolved and suspended sediment and differences in temperature and emissivity between the saltwater and the inflowing freshwater.

Freshwater/saltwater boundaries or intermediate brackish conditions exist also in many coastal estuaries, marshes, and swamps. Tides, storms, seasonal changes in rainfall, surface runoff, and groundwater levels cause fluctuations in the location of general freshwater, brackish, and saltwater zones. The vegetation in the coastal marshes and swamps typically reflects the local variations in water quality and topography and can be used as a general indicator of distinct zones and interfaces.

Also, in coastal areas an interface typically exists between fresh groundwater and saltwater in subsurface aquifers. The position of this interface can also fluctuate widely depending on a variety of factors. Various geophysical techniques can be used to detect the level of occurrence of subsurface water, but it is uncertain whether interfaces can be defined accurately by remote sensing techniques.

(c) Remote Sensor Applications: Tonal differences indicative of freshwater, saltwater, and brackish water areas and interface zones can be discriminated on panchromatic and ultraviolet photography. Multiband photography should also be useful for defining water differences and interface zones.

Color and color IR photography have been widely used for differentiating freshwater, saltwater, and intermediate brackish water areas and interface zones. Subtle

differences in water tones can be generally detected more easily, and the discrimination of vegetation indicators is also made easier with these films. Color photography has been used by Paulson (1968) and Duxbury (1967) to determine freshwater/saltwater interfaces marked by turbulence and discoloration.

In a study of the Everglades of Florida, Schneider (1966) reported on the clear delineation between freshwater and brackish water marshes that could be made on color photographs. Inland tidal estuarine channels were also easily identified by their thick assemblages of mangrove trees.

Pestrong (1969) points out the particular value of color IR transparencies for studying the distribution of vegetation in a saltwater marsh.

Areas of freshwater flow into saltwater and the location of interface zones can be determined on the basis of temperature and emissivity differences. Thermal infrared and passive microwave sensors have obvious application here, and their use has been discussed by numerous authors among whom are Snavely and MacLeod (1969) Taylor and Stingelin (1969), and Wiesnet and Cotton (1967).

Radar imagery provides a small-scale format for studying the fluvial/marine hydrologic environment of coastal areas. Shorelines, tidal flats, and mangrove swamps along the shoreline and estuarine channels show up well on quality, high-resolution SLAR imagery (Macdonald, *et al.*, 1971). These features can be used to separate the freshwater, brackish, and saltwater areas but only in a very general way.

113. ICE THICKNESS

(a) Definition: A determination or measure of the vertical distance from the air-ice or ice-snow interface to the underlying water ice interface.

(b) Interpretation Variables: To treat this broad subject logically, a distinction must be made immediately between floating ice (sea ice, lake ice, etc.) and land ice (freshwater ice in the form of glaciers, ice caps, etc.). Each category could be the subject of a lengthy analysis. In addition, floating ice should be divided into freshwater ice and sea ice because of differences in occurrence and physical and chemical properties (and, hence, different effects on electromagnetic radiant energy). The distinctions between various ice types are more fully developed under the MGI element 115 (Ice Type) and should be read in conjunction with this presentation.

Recently, there has been much interest in floating ice especially sea ice in the Arctic. A meeting was held in Ottawa, Canada, October, 1970, entitled "Seminar

on Thickness Measurement of Floating Ice by Remote Sensors." This seminar can be considered a summary of the state-of-the-art on the subject.

As with other MGI elements, a distinction can be made between sensors which yield direct quantitative data of reasonable accuracy (in this case on ice thickness) and those sensors which provide data by which subjective determinations can be made.

Thickness determination of sea ice is a special problem, and such determinations rely heavily on subjective inferences based on ice type. Such techniques have proven satisfactory since mostly class type information on ice thickness (e.g., 4-8 feet) has been necessary for mobility purposes. Thus, any sensor yielding data which helps differentiate sea-ice types is useful for determining ice thickness; these sensors are discussed at length under 115 (Ice Type).

An interpreter knowledgeable of sea ice and its seasonal changes, especially in a specific area, can make good judgments of ice thickness. Of course, the adequacy of these judgments would depend on their reliability and on the purpose for which the information is needed.

There are also many studies on sea-ice growth and thickness based on air-temperature history, statistical treatments of long-term ice observations, and complex theoretical analyses; these are generally limited to specific areas. A listing of some of these studies is given by Maykut and Untersteiner (1971). Such studies can aid in thickness determinations although they are limited in usefulness because ice is not a flat, uniform, static material but is dynamic in all aspects and large variations can be expected. Sea ice in the Arctic can range in thickness from a fraction of an inch for surface glaze to tens of feet for pressure-ridged ice. The biggest problem in this regard is winter ice in the open ocean. It is the type of ice most frequently encountered and most variable in its characteristics including thickness and roughness. Snow cover is an additional variable which can hinder ice-thickness determination.

(c) Remote Sensor Applications: Photography of all kinds has been commonly used for sea-ice type identification. Non-stereo imagery can be used, but stereo coverage is desirable for any detailed analysis. Panchromatic and panchromatic IR are the most frequently used films, but color and color IR films also have value especially for situations such as ice in a melting environment. The age of sea ice can sometimes be relatively determined on color film, the older ice characteristically exhibits a distinct blue color. Multiband imagery may also have similar usefulness.

Thickness estimates and, also, direct measurements are possible from photographic imagery of appropriate scale, resolution, and metric quality. Anderson (1970) discussed procedures for measuring upturned blocks of ice (standing floes). He considered

the imagery scale (panchromatic) of 1:4,364 adequate for the simple measuring technique used (calibrated hand magnifier); but he would have preferred a scale on the order of 1:2,000 (personal communication). Such measurement, of course, can be made more accurately with more sophisticated equipment. The height of pressure ridges can also be used as a general indicator of ice thickness.

For lake and river ice, it may be possible for an interpreter knowledgeable about these forms of ice to make good estimates of ice thickness. Measurements can probably also be made of rafted and upturned ice following the procedures outlined by Anderson (1970) for sea ice. Color and color IR films may be especially useful in riverine environments.

For extensive freshwater ice masses such as glaciers, ice fields, and ice caps, photography can be used to estimate and measure their overall dimensions. Thickness determinations, however, will be largely limited to approximations based on the nature and extent of surface features and the inferred bottom level of the ice mass.

Photography can also be used to ascertain the thickness of bergs and ice islands–at least that portion above the waterline. Overall dimensions, however, can only be determined by assuming a given shape for the underwater portion and applying flotation values based on the average density of freshwater ice (also allowing for the sea ice which commonly occurs on the bottom of these bergs and islands). The accuracy of such a technique remains to be determined.

As has been demonstrated, thickness determinations of ice from photography depend a great deal on the skill and knowledge of the interpreter. The photography is largely a convenient format for viewing the ice conditions. Skill is an even more important factor when imagery from more exotic sensors is used.

Thermal IR and microwave imagery can be used for determinations of sea-ice thickness in much the same manner as outlined for photography – identification of ice types. In addition, the variations in signal intensity can be used as a direct indicator of ice thickness, although such variables as snow cover can complicate the procedure. The resolution of these sensors is not as good as photography (microwave is especially poor) and the image geometry is more complex. These sensors, however, permit nighttime acquisition of data, and, in addition, the microwave system is not significantly affected by haze, fog, or clouds. As with photography, the usefulness of IR and microwave imagery depends on, among other things, the image quality, scale, type of ice being monitored, accuracy desired, and the extent of the area of interest.

High-frequency radar (SLAR) imagery has been commonly used for sea-ice reconnaissance. The essentially all-weather and day-night capabilities of the SLAR make

it a valuable tool especially in the Arctic. Radar permits a rapid reconnaissance of large areas, and the resolution is sufficient for mapping general ice distribution, types, and large leads; it should be equally as effective for freshwater lake ice. This type of radar is also useful for mapping glaciers and ice caps and for locating bergs (some limitations, however, for berg detection—see discussion under 115 (Ice Types)). High-frequency radar has a limited penetrating capability (especially on sea ice), and ice-thickness determinations can be made only by the inference procedures outlined under photography.

UHF, high-resolution, monocycle-pulse radar has been successfully used to monitor the thickness of freshwater lake ice (Meyer, 1966; Rinker, 1966). The effective depth of penetration for these systems was about 450 to 700 cm, and ice as thin as 11 cm could be resolved for measurement. Test results were good under ideal lake-ice conditions. Problems arise with uneven, inhomogeneous surfaces and interfaces, and the system is probably not effective on hummocked lake and river ice. The monocycle radar technique does not work on sea ice because of the strong attenuation of radar frequency energy by the liquid brine cells common in sea ice and the gradual change in bulk-ice density with depth which virtually eliminates a distinct signal return from the ice/water interface.

Low-frequency (long wave) radar has been used successfully for airborne sounding of freshwater glaciers and the thick ice caps of Greenland and the Antarctic (Rinker, *et al.*, 1966). These measurements show good agreement with data gathered by ground seismic surveys. There is a decreasing resolution with increasing wavelength (antenna size and other problems), but errors are minimal in relation to the extreme thicknesses monitored.

The air-droppable penetrometer has proven to be an accurate sensor of sea-ice thickness (McIntosh, 1970) and, no doubt, can be used for freshwater ice as well. The penetrometer provides only point data, has a limited depth of penetration in ice, but has good accuracy (within a few centimeters) and may be valuable for specific studies and problems especially if low-cost, disposable models can be developed.

The laser profilometer can provide valuable data on surface roughness of sea, ice (ridges, etc.) and extent of open water. Statistical treatments of this data can yield information on ice types from which thicknesses can be inferred. This data is valid, however, only for the linear area traversed by the laser, and supplemental imagery would have to be used to extend ice type and thickness determinations over wider areas. The laser profilometer is a commercially available sensor which can operate in daylight, and its data can be stored and treated automatically.

Other specialized techniques for remotely determining the thickness of sea ice and floating ice in general are currently being experimented with. Some of these techniques are discussed by Adey (1970).

Environmental factors affecting the acquisition and interpretation of remote sensing imagery for ice thickness determinations are essentially the same as those discussed under 115 (Ice Types).

114. LOCATION AND ALIGNMENT OF ICE LEADS, FRACTURES, AND RIDGES

(a) Definition: A determination of the location, alignment, and general dimensions of the major openings and linear zones of weakness and obstruction occurring on and within floating ice masses.

(b) Interpretation Variables: Recognition and location of the above features are important for ship travel through extensive sea-ice cover, for surface travel across the ice, and for aircraft landings on the ice. These mobility problems affect freshwater floating ice as well. Ice on small streams does not present the same problems as ice on rivers and lakes, however, it is still desirable to know the distribution of ice, open water areas, and zones of weakness and roughness even on small streams.

Sea ice can serve as an approximate model for the above features. It is the most extensive floating ice type, reaches the greatest thickness, and contains the most striking examples of leads, fractures, and ridges. The conclusions reached as to effective sensors for reconnaissance of these features on sea ice, hopefully, can be applied to freshwater floating ice with appropriate modifications in scale, etc.

Ridges are a type of pressure ice and are formed when, because of compressive forces acting within the floating ice mass, floes are pressed together and forced upward along fracture zones. They may reach several tens of feet in thickness. The ridges can be identified by their irregular linear patterns, vertical relief and roughness (which may be highlighted by shadows), and associated snow banks which tend to form against them.

Other types of pressure ice can also occur: Ice floes may override one another (rafted ice), floes may be upturned and wedged between adjacent floes in a vertical or near vertical position (standing floe), or ice may pile up in a jumbled mass (hummocked ice). Recognition and location of all types of pressure ice are important for mobility purposes.

Variable forces acting within the shifting ice mass also give rise to numerous fractures. These can be cracks of little displacement or large navigable openings or

leads. The leads may subsequently freeze over but the ice cover will be generally thinner than the surrounding floes. Leads can be detected and recognized by their characteristic elongated pattern and contrast between open water and adjacent ice. Differences in reflective and thermal properties of the ice/water interfaces provide the basis for detecting leads with a variety of active and passive remote sensors.

Imaging sensors are the most useful for detecting leads, fractures, and ridges on floating ice. With imagery (stereo especially), the linear patterns of these features can be readily recognized and their distribution mapped.

(c) Remote Sensor Application: Photography of all types can provide information on location, alignment, and overall dimensions of leads, fractures, and ridges. Panchromatic and panchromatic IR are most commonly used. Anderson (1971) gives an example of the use of large scale (approximately 1:4,400) panchromatic photography (stereo) for a detailed analysis of leads, ridges, and general ice conditions in a local area of the Arctic Ocean. Measurements of ridge heights, especially, require large-scale stereo imagery. Generally, leads are more readily identifiable on small-scale imagery than are pressure ridges. Panoramic photography has proven to be especially useful for sea-ice reconnaissance (Biache, *et al.*, 1971).

Color and color IR can provide additional information and contrast (especially on leads) where maximum definition is needed between snow, ice, and open water. For similar reasons, multiband photography would also be useful. Use of these more exotic films and techniques, however, would have to take into consideration cost and other factors which may limit their use to local areas and special ice studies.

Low-sun-angle photographic techniques may help to outline ridges and other relief features on the ice but would be less desirable for detecting leads. Special, low-light-level photographic systems may have usefulness for acquiring imagery under twilight conditions and even at night under optimum atmospheric conditions.

IR scanner imagery can also be used to detect ice leads, fractures, and ridges. Open leads especially provide excellent thermal contrasts. Areas of thin ice should also be generally distinguishable from areas of thick ice – the thinner ice areas exhibiting generally warmer tones on the imagery. Variable snow cover and meltwater pools on the ice, however, can minimize thermal contrasts or cause anomalous signals. Such environmental factors as these, as well as diurnal and seasonal changes in the general ice environment, must be kept in mind when analyzing ice conditions on IR imagery. Pressure ridges, for instance, normally appear "cold" on nighttime and diffused daylight imagery, but under strong sunlight the sun-oriented faces of the ridges can give very warm returns.

Microwave scanners also permit imaging of ice conditions at night and under atmospheric moisture conditions that would inhibit use of thermal IR. Spatial resolution is poor; but large features, especially leads, should be readily detectable. Microwave energy is not totally unaffected by atmospheric moisture; however, low cloud cover, for instance, can raise the microwave brightness temperature of water (has low emissivity and normally appears cold) thus lessening the contrast between ice and snow (Strong and Fleming, 1970).

Television-type systems have good resolution and are useful for monitoring ice conditions in real time, permanent images can also be obtained. Such sensors can be a valuable part of an overall ice reconnaissance system as outlined by Harwood (1968) and Biache, *et al.* (1971).

Radar, especially SLAR, permits the rapid imaging of sea-ice conditions over wide areas. Despite generally small scales and limited contrast, ice types can be identified, land margins outlined, large bergs, floes, and ice islands identified, and intervening leads detected. On quality imagery of larger scale (depending on type of radar, scanning mode, altitude, etc.), large pressure ridges can be identified and traced. Anderson (1966) shows examples of conventional, high-altitude radar imagery of sea ice and discusses various features which can be identified. Use of stereo radar imagery would greatly enhance the analysis of ice features—especially pressure ridges.

Leads, fractures, and ridges may be identified, and their distributions may be mapped from quality photographic imagery by a less-experienced interpreter. This is generally true, also, for scanner and radar imagery, however, there will be instances when, because of anomalous returns, etc., an interpreter will be needed who is familiar with the basics of these sensors and the effects of environmental variables.

Airborne laser systems can provide valuable statistical data on frequency of occurrence and vertical dimensions (less reliable for horizontal dimensions) of ice leads, ridges, etc., over a given flight path. The difficulty of maintaining azimuth and knowing true ground speed, however, gives rise to location problems and lessens the utility of the laser system for detailed studies.

Some discussion has already been made of the environmental variables affecting the acquisition and interpretation of remote sensor imagery for the purpose of detecting and recognizing ice leads, fractures, and ridges. Other environmental factors common to ice reconnaissance are discussed under 115 (Ice Type).

115. ICE TYPE

(a) Definition: A determination of the type of ice mass based on origin, chemical and physical properties, morphology, and stage of development.

(b) Interpretation Variables: This is a broad category and for any detailed discussion should be subdivided into several subcategories. Sea ice alone would merit individual attention. An attempt, however, will be made to cover the major ice types although sea ice will be discussed in more detail than others. Major ice accumulations can be divided into land ice and floating ice. Floating ice can be subdivided into fresh-water and saltwater ice or sea ice. Floating ice is the most widespread type in areal extent—sea ice alone making up nearly two-thirds of the earth's ice cover (Maykut and Untersteiner, 1971). The freshwater floating ice cover fluctuates greatly with seasonal warming and cooling and generally disappears in lakes and rivers even in the high altitudes. The sea-ice cover, confined largely to the polar latitudes, also fluctuates seasonally but not as greatly, and a certain portion—the polar ice packs—remains from season to season.

Bergs and ice islands are special forms of floating ice. These are masses of freshwater ice derived from glaciers and ice shelves of land areas. The bergs and ice islands can be of great dimensions (some ice islands in the Arctic Ocean are used as floating scientific observatories) and commonly have saltwater ice attached to their bottoms.

Land ice is freshwater ice occurring as small seasonal accumulations and as larger more permanent masses on the land surface. Considerable ice also occurs within frozen ground, but this mode of occurrence will not be discussed here. Land ice can range from small ground-water-fed icings a few feet thick, to very thick ice in the form of glaciers and icefields, to extremely thick and extensive ice caps. The Greenland ice cap, for example, covers an area of about 666,000 square miles, averages about 5,000 feet in thickness, and reaches a maximum thickness of about 10,000 feet (Bader, 1961).

The identification of general ice types is relatively straightforward since the location and mode of occurrence indicate its origin and composition. Such general determinations will be treated only briefly. General treatments of the geographical and geomorphological aspects of major ice forms are given by Thornbury (1954) and Flint (1957). Glaciers are considered in more detail under 310 (Location of Glaciers).

A brief classification of major sea-ice types, presented below, is extracted from the comprehensive manual "MANICE" (Amendment #5) published by the Canadian Department of Transport, 1965:

New Ice: A general term for recently formed ice which includes frazil ice, grease ice, slush, and shuga. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.

Nilas: A thin elastic crust of ice bending on waves and swell and under pressure, thrusting in a pattern of interlocking "fingers" (finger rafting). Has a matte surface and is up to 4 inches in thickness.

Young Ice: Ice in the transition stage between nilas and first-year ice; 4-12 inches in thickness.

First-year Ice: Sea ice of not more than one winter's growth, developing from young ice; thickness from 12 inches to 6 feet or more.

Second-year Ice: Old ice which has survived only one summer's melt. Because it is thicker and less dense than first-year ice, it stands higher out of the water. In contrast to multi-year ice, summer melting produces a regular pattern of numerous small puddles. Bare patches and puddles are usually greenish-blue.

Multi-year Ice: Old ice up to 9 feet or more thick which has survived at least two summers. Hummocks are smoother than in second-year ice, and the ice is almost salt-free. Color, where bare, is usually blue. Melt pattern consists of large interconnecting irregular puddles and a well-developed drainage system.

The first-year, second-year, and multi-year ice are of special interest since these types are the thickest. These ice types have characteristic patterns which serve to identify each. The multi-year ice, for instance, is characteristically extremely jumbled, broken, and pressure-ridged; it makes up the bulk of the "pack ice."

Freshwater floating ice can also have similar classifications (the terms multi-year ice, second-year ice, etc., however, do not, generally, apply to freshwater floating ice). In fact, much of the terminology used to describe freshwater ice is similar to that used for sea ice (Michel, 1971). Many features such as hummocked ice and pancake ice are common to both ice regimes. Such common ice terms are described in numerous glossaries some of which are listed by Michel (1971)

The identification of the various types of sea ice is an important problem. Much of the information that is derived on sea ice through remote sensing techniques is done by the identification of major ice types. Many attributes, such as thickness and roughness, are associated with specific sea-ice types. Generally, only broad class-type data is required (for example, thickness class 4-8 feet), and much of this type of information can be obtained from remote sensor imagery on which sea-ice types can be identified and distributions mapped.

(c) Remote Sensor Applications: Photographic systems have commonly been used for general investigations of various ice types and forms in all environments. These investigations range from general reconnaissance mapping to specific detailed analysis. Measurements can also be made on stereo photography. Useful scales depend on the type of ice being imaged and the information requirements, but, generally, useful scales can be quite small.

Panchromatic and panchromatic IR are the most commonly used films for ice studies, but color and color IR films can provide much additional information especially in situations such as ice in a melting environment (good definition of ponded water on ice), local icings, and ice on rivers where good boundary definitions are required. The relative age of sea ice can sometimes be ascertained on color film—the older ice exhibiting a distinct blue color. Limited exposure latitudes, however, tend to restrict the use of color films in polar regions.

Acquisition of photographic imagery is usually largely confined to daylight and to relatively clear atmospheric conditions. Special low-light, camera-film systems may permit imaging of ice at night under special conditions, e.g., full moon and clear atmosphere. Visibility over ice at night under such ideal conditions can be very good.

An example of the type of detailed analysis that can be carried out on sea ice using large-scale panchromatic photography is provided by Anderson (1970). Ice types are identified and discussed and thickness measurements made on upturned floes.

Thermal IR scanner imagery has been used for investigation of a variety of broad ice types. Spatial and thermal resolutions are good. The spatial resolution of conventional unclassified systems can be on the order of 1 foot in a 1,000 feet and thermal resolution, on the order of .5° C. Newer systems probably have greater sensitivities. The IR scanner can be used as a prime sensor or as a supplementary sensor to photography. IR radiometers can also add valuable quantitative thermal data.

Use of IR imagery ranges from detecting crevasses on glaciers and ice caps to studying the thermal regime of ice-covered rivers. Maximum effectiveness is gained

by acquiring imagery at times when signal contrasts will be greatest which may be at various times during the day or night.

The thermal IR scanner has proven to be a useful reconnaissance sensor for sea ice. Ice types can be readily identified, and, under good meteorological conditions, high altitude flights can be made and wide coverage obtained. Use of IR imagery also allows the detection of frozen, snow-covered shorelines of low relief which are not readily observable or are completely undetectable on conventional imagery (Poulin and Harwood, 1966; Poulin, in preparation). The technique should also work in similar freshwater situations.

Sea-ice types are identified from IR imagery by tonal contrasts indicating differences in thermal response and by surface roughness and other ice patterns. While, in general, thermal signals will be a function of ice thickness (thick ice appearing colder than thin ice), variable snow cover and variable seasonal and meteorological conditions can affect the thermal signal. Reliance on tonal contrast alone can yield misleading data on sea-ice types. Such factors limit the usefulness for sea-ice type identification of data obtained automatically from density traces of IR imagery or from direct processing of thermal signals.

The most commonly used thermal IR band is the 8 to 14 micrometer band which in its upper limits is a "window" band to CO_2 in addition to H_2O and O_2. IR radiant energy is not totally unaffected by atmospheric moisture, however; and it is sometimes desirable to fly an IR spectrometer in conjunction with a scanner to determine the degree of attenuation of the thermal IR signal, especially at night when it is difficult to judge atmospheric conditions. The use of IR spectrometer bands of other than "window" wavelengths will give indications of atmospheric moisture conditions which can be allowed for in the scanner imagery.

Passive microwave scanners have also been used for sea-ice reconnaissance especially by the U. S. Coast Guard for detection of icebergs in heavily used shipping lanes (Harwood 1969). Despite poor spatial resolution, microwave scanners are useful for berg detection because radiant energy at microwave frequencies is essentially unaffected by thick haze or fog - a condition which exists over areas such as the Grand Banks for much of the iceberg season. In addition, microwave imagery can be obtained at night. However, microwave has some limitations for berg detection in that the thermal "brightness" of an iceberg can have a wide range and the berg can be confused with a ship having a low thermal output (Harwood, 1969).

Microwave scanners should be useful also for delineating frozen, snow-covered shorelines in a manner similar to thermal IR. Currently, there is much interest

in and experimenting with microwave sensing techniques (Porter, 1970; Porter and Florence, 1969).

Radar is also used for berg detection but is limited in usefulness in shipping areas in that it sometimes generates similar returns for ships and bergs (Harwood, 1969). Despite some shortcomings, high-frequency radar, in particular SLAR, is a widely used sensor for sea-ice reconnaissance because of its all-weather day/night capability and its ability to image large areas on small amounts of film. Despite limitations in resolution and tonal contrasts, gross surface patterns can be detected, ice types identified, and distributions mapped rapidly on radar imagery. Many different radar systems have been used for sea-ice reconnaissance using various bands (X, Ka), and multifrequency bands have also been experimented with (Guinard, 1969). Radar can also provide good coverage on the distribution and major features of freshwater lake ice and can be used for mapping various large-surface features and boundaries on glaciers, ice sheets, and ice caps (see element 310 (Glaciers)).

The radar scatterometer has also been used to identify sea-ice types based on differences in scattering coefficients in the 2.25 cm wavelength band (Rouse, 1968).

The laser profilometer can be used for differentiating sea-ice types based on surface roughness. The system yields only line trace data, but these data can be stored and processed automatically–a valuable feature for rapid mapping of sea-ice types. The possibility of developing a laser scanner has been mentioned by Harwood (1969), such a system would yield a broader path trace but would have obvious disadvantages which would have to be reconciled. The laser profilometer can also yield valuable data on surface characteristics of ice other than sea ice, but it would not be used as a primary sensor for identification of these other broad ice types.

The environmental factors affecting the remote sensing of various types of ice have been discussed briefly in relation to some of the individual sensor systems. These environmental factors are mostly meteorological. Haze, fog, and clouds affect the acquisition and interpretability of photographic imagery, laser traces, and thermal IR imagery. Nighttime operations are largely limited to radar, microwave, and thermal IR sensors, appreciable atmospheric water vapor, however, restricts the nighttime use of thermal IR sensors. Acquisition of remote sensor imagery in the polar regions is complicated by long periods of darkness during the winter and appreciable cloud cover during the summer.

Winds are another environmental factor because they can erase surface thermal signals and cause drifting of snow. Variable thickness of snow cover on land and ice can mask minor surface features and conceal fractures, such variations of snow thickness and density can also give rise to anomalous thermal and radar signals.

Temperature inversions, especially at night, can also give rise to anomalous thermal signals. Such environmental factors must be kept in mind when a remote sensing mission is planned or when imagery is analyzed.

116. LOCATION OF SPRINGS

(a) Definition: A determination of the location of groundwater issuing from a natural opening in such quantity as to make a distinct flow.

There are other elements in this report that contain information pertinent to the detection of springs, these should be read in conjunction with this presentation—particularly 307 (Soil Moisture Content), 111 (Type of Water Pollutants), and 120 (Location of Groundwater).

(b) Interpretation Variables: Water from springs may issue on the land surface or flow directly into a water body such as a stream or lake. Various vegetation assemblages may indicate the presence of springs, especially in arid regions. Springs issuing into water bodies may give rise to distinct tones because of differences in water quality, etc., which may be detectable on remote sensor imagery—particularly photography. The springwater frequently is at a different temperature than the water body and is also detectable on this basis. Differences in emissivity also make detection possible particularly where freshwater springs issue into saltwater bodies. The generally limited volume of flow from springs can make their detection difficult; large-scale imagery is generally desirable. It may be advantageous to acquire imagery during dry periods when springs should theoretically be more easily detected and other types of water flow reduced.

(c) Remote Sensor Applications: Photography of various types can be used to record and identify the indicators of springs. Color and color IR films have special use for locating springs having associated assemblages of lush vegetation. Color and color IR films are also especially useful for detecting the subtle tonal differences in water bodies that may indicate the presence of springs.

Multiband photography can provide a broad basis for reconnaissance detection of springs occurring on the land surface and in water bodies.

Thermal IR imagery has been widely used to detect springs. Both the 3- to 5.5- and 8- to 14-micrometer bands have been employed. Lee (1969) has been able to detect springs discharging into Mono Lake, California (a saline lake). The flow of some springs was as low as a few liters per second. In many oceanic coastal areas, such as in Hawaii, fresh groundwater flowing into the ocean has been detected by thermal imagery. Geothermal springs in the Yellowstone Park area have also been detected on thermal

imagery. Stingelin (1969) notes that springs are especially detectable on nighttime, winter thermal imagery when air temperatures are well below freezing.

Passive microwave imagery can be used to detect springs in a manner similar to thermal IR although spatial resolution is not as good.

Radar imagery, particularly SLAR, can be useful for detecting springs and for water-resource investigations in general. The imagery provides a small-scale layout of the major features of the landscape, such as topography and drainage, and can be used to evaluate the broad conditions of overland and subsurface flow including the locations where springs may occur. Only very general determinations can be made, however, and other types of imagery or supplemental information must be used.

117. LOCATION OF GEOTHERMAL WATERS

(a) Definition: A determination of the location of surface water that has issued from the subsurface after being heated by geothermal sources.

(b) Interpretation Variables: Geothermal springs and other hydrothermal features such as geysers occur in generally restricted areas on the earth's surface. Their most distinguishing characteristic is the abnormally high temperature of the water. Many of the methods and techniques used to detect springs, seeps, etc., of normal temperature (see 116) can also be used to detect their geothermal counterparts, however, the most obvious way to detect these features is to employ thermal sensors.

(c) Remote Sensor Applications: Thermal infrared scanner imagery has been widely used to detect geothermal waters. Both the 3- to 5- and 8- to 14-micrometer wavelength bands have been employed. Large-scale imagery is desirable. Imagery can be obtained at night or early morning when the contrast between thermal waters and surroundings is greatest. McLerran (1967), however, has shown that imagery obtained during late morning has the best potential for differentiating between geothermal and non-geothermal springs.

Geothermal waters characteristically exhibit greater than normal amounts of radioactivity and may also be detectable on this basis.

118. AREA OF SWAMP

(a) Definition: Area of water-saturated land dominated by trees and shrubs.[2]

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[2] Department of the Army, 1959, "Terrain Intelligence," Manual FM 30-10.

(b) **Interpretation Variables:** To estimate or measure the area of a swamp, marsh, or similar wetland feature, the feature must first be recognized, identified, and bounded. Determining exact boundaries can be difficult; however, there is generally enough topographic variation associated with a swamp or marsh to allow delineation of major boundaries. The geometry of various types of remote sensor imagery for accurate measurement of area is briefly discussed under "Area of Surficial Deposit" (303).

Aerial photography has been commonly used in the past to investigate swamps, marshes, and wetland areas in general. Panchromatic photography has probably been the most commonly employed. In recent years, color and color IR photography have been increasingly utilized. These films have obvious advantages for studying the varied elements of wetland terrain. Recent work has also been directed toward the automatic interpretation of swamps and marshes. Multispectral data in 10 bands between 0.4 to 1.0 micrometer obtained from a flying height of 2,000 feet has been automatically processed to outline swamps (Kolipenski, *et al.*, 1969). Waveform analyses of grey tones of infrared imagery and panchromatic photography have been applied to the automatic delineation of swamps (Latham and Witner, 1967).

(c) **Remote Sensor Applications.** An evaluation of multiband photography (nine lens camera. bands between .4 and .9 micrometer) and supplemental photography (panchromatic, Ektachrome, and Ektachrome IR) was carried out on a tidal marsh area in San Francisco Bay by Pestrong (1969). Some of his conclusions were:

(1) Near infrared photography was superior for detection of drainage channels and for determining boundaries between land and water.

(2) The Ektachrome IR photography was superior for differentiation of the various types of vegetation in the marsh. There was a close correlation between vegetation types and marsh topography.

(3) For overall interpretive purposes, Ektachrome color transparencies were most useful.

Smith (1963) points out the usefulness of color photography for delineating swamps and marshes and their drainage patterns.

Thermal infrared scanning devices employing the 3- to 5-micrometer band have been applied to the study of swampy areas (Stingelin, 1968). The infrared images clearly distinguish the areas of saturated ground. An infrared survey should probably be accompanied by some type of photography to clearly depict trees and other types of vegetation.

119. AREA OF MARSH

(a) Definition: Area of water-saturated land dominated by grass-like, aquatic vegetation.[3]

(b) Interpretation Variables: Much the same considerations apply to the delineation of marshes as to swamps. For the remainder of this discussion, refer to "Area of Swamp" (118).

(c) Remote Sensor Application: Refer to (118).

120. LOCATION OF GROUNDWATER

(a) Definition: A determination of the presence in subsurface strata of a water-saturated zone.

(b) Interpretation Variables: The upper limit of the zone of water saturation in rocks and soils is known as the groundwater table. Its depth of occurrence and its fluctuation in an area depend on many factors some of which are climate, topography, and structure and type of rocks and soils. A regional groundwater table may exist in an area along with many local "perched" zones of saturation at levels above the regional table.

Determining the presence and depth of groundwater in an area from remote sensor imagery is largely an interpretive procedure requiring the skills of an experienced worker. Many complex observations and judgments must be made. An area must be considered in total because of the many factors determining the occurrence and depth of groundwater. The interpreter utilizes numerous clues in determining the presence of groundwater and its probable depth, these include drainage characteristics, the type and distribution of vegetation (especially important in arid regions), land use, and cultural features such as artificial ponds, ditches, and wells. Special attention is paid to plains and valleys and low areas in general. The surface materials are evaluated, and areas of excessive soil moisture or standing water are noted. Howe (1958) outlines a comprehensive procedure for evaluating the groundwater conditions in an area.

Other elements in this report also contain information related to the general subject of location of groundwater, especially 307 (Moisture Content of Surficial Deposit) and 116 (Location of Springs).

[3]Department of the Army 1959, "Terrain Intelligence," Manual FM 30-10.

(c) Remote Sensor Applications: A variety of remote sensors can be used to provide data for interpreting groundwater conditions. Probably the most widely used is photography. Photography provides a convenient format for viewing the landscape as it appears naturally (especially true for color photography). Small-scale photos (or mosaics) can be used for a regional analysis, and photos of larger scale can be used for investigating local conditions of groundwater occurrence. Such a regional-to-local approach is advocated by Howe (1958).

Panchromatic and panchromatic IR films can be used advantageously for general groundwater evaluations (Howe, 1958: Chase 1969). Because the interpretation of groundwater conditions in an area involves the evaluation of many diverse natural and cultural landscape features, it would appear that color and color IR films would generally yield the best overall results. The merits of these films in terms of ease of recognition and interpretation of soils, soil moisture, drainage, vegetation, and cultural features have been discussed in many articles.

Schneider (1968) mentions that the proper identification of key indicators of subsurface water may be enhanced by the use of color photography.

Multiband photography would also be useful for analyzing groundwater indicators in diverse terrain.

Thermal IR and passive microwave imagery can provide useful data for evaluating groundwater conditions. The imagery is probably best used in conjunction with photography. The imagery can aid in locating drainage features such as small water bodies, streams, seeps, and springs and for evaluating relative soil moisture levels. L[illegible] areas of high-surface soil moisture can produce distinct thermal tones on IR imagery; such areas may have locally shallow water tables. Subsurface soil moisture can also influence the surface temperature and the general nature of subsurface materials indicated by surface thermal responses. Coarse, well-drained materials such as sands and gravels may have little surface moisture but contain appreciable groundwater at depth. Wermund (1971) reports good correlation of microwave and thermal IR radiometer measurements over known groundwater sites in arid terrain.

Care must be taken when analyzing thermal imagery that tones are not hastily attributed to the effects of soil moisture. Such misleading tones can be produced, for instance, by the pooling of cold air in low areas as reported by Wolfe (1968). Imaging missions should be planned to obtain maximum contrasts of ground signals. Good results have been obtained with imagery acquired a few hours before dawn. Factors that should be considered when planning a thermal mission include the type of area, general nature of surface materials and vegetation, season, and previous meteorological conditions (heavy rainfall, etc.).

Radar imagery, particularly SLAR, has some use for inferring the presence and probable depth of groundwater in an area. The generally small-scale imagery allows an appraisal of the major components of the landscape which are important for evaluating groundwater conditions. These include topography, structure, drainage, gross vegetation types, and major soil and rock units. The chief value of the radar imagery, thus, is for appraising the overall "setting" of an area. Other types of remote sensor imagery, such as photography, will be needed to make more detailed and reliable determinations of groundwater conditions.

Indications are that surface soil moisture in general affects the strength and polarization of return radar signals, particularly at shorter wavelengths. Tests by Davis, *et al.* (1966), indicate that long-wavelength (P band) radar signals can within limits penetrate soils, and the presence of groundwater can be detected by characteristic reflections from the subsurface soil/water interface. Such preliminary results show promise for radar as a tool for remotely determining by direct means the soil moisture and groundwater conditions of terrain.

Various airborne and surface geophysical techniques have been used for determining the presence and depth of groundwater. Among the relatively new airborne techniques are the INPUT system reported by Barringer (1966) and the E-Phase TM system reported by Barringer and McNeil (1971). Adams and Lepley (1971) report on the use of a ground based Audiomagnetotelluric system in Hawaii for determining the depth to groundwater and for making other judgments on subsurface characteristics.

The air-droppable penetrometer may also have application for determining the depth to groundwater at a given location.

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Table II. Drainage and Water Elements

MILITARY GEOGRAPHIC INFORMATION REMOTE SENSOR MATRIX		PANCHROMATIC				COLOR				COLOR IR				PAN IR				MULTI-BAND	NARROW BAND	TV	MULTI-SCANNER	IR SCANNER	MICROWAVE	KA RADARS	LF RADARS	GAMMA RAY	RADIOMETRIC-SPECTROMETRIC	LASERS	MAGNETOMETRIC	GRAVIMETRIC	SPECIALIZED ELECTROMAG	PENETROMETER
*	A	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
101 DEPTH OF WATER BODY	1	C 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	B 1	B 1	1	1	0	0	0	0	X	X	1	X	X	0	1
102 VELOCITY OF WATER FLOW	1	C 1	1	1	1	A 1	1	1	1	B 1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	X	X	0	X
103 BANK/SHORE LOCATION	2	2	2	2	2	B 2	2	2	-	A 2	2	2	2	C 2	2	2	2	2	2	2	2	1	1	1	1	X	0	1	X	X	0	X
104 BANK/SHORE COMPOSITION	1	1	1	1	1	A 1	1	1	1	C 1	1	1	1	1	1	1	1	B 1	B 1	1	1	1	1	1	1	0	0	0	0	X	0	1
105 BANK/SHORE SLOPE	1	B 1	1	1	1	1	1	1	1	1	1	1	1	A 1	1	1	1	1	1	1	1	0	0	1	1	X	X	C 1	X	X	X	0
106 BANK/SHORE HEIGHT	1	B 1	1	1	1	1	1	1	1	1	1	1	1	A 1	1	1	1	1	1	1	1	0	0	1	1	X	X	C 1	X	X	X	0
107 BANK/SHORE STABILITY	1	C 1	1	1	1	A 1	1	1	1	B 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	X	X	0	0
108 AREA OF FLOODING	2	B 2	B 2	2	2	2	2	2	2	2	2	2	2	A 2	A 2	2	2	-	2	2	2	1	1	C 1	C 1	X	X	X	X	X	X	X
109 STREAMBED COMPOSITION	1	C 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	B 1	B 1	1	1	1	1	1	1	0	0	0	0	X	0	1
110 STREAMBED GRADIENT	1	B 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	C 1	C 1	1	1	0	0	1	1	X	X	1	X	X	X	X
111 TYPE OF WATER POLLUTANTS	1	1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	B 1	B 1	1	1	C 1	1	1	1	1	0	1	X	X	0	X
112 FRESH/SALTWATER INTERFACE	1	1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	B 1	B 1	1	1	C 1	1	0	0	0	0	0	X	X	0	X
113 ICE THICKNESS	1	A 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	B 1	1	C 1	C 1	X	0	0	X	X	1	1
114 LOCATION ALIGNMENT LEADS FRACTURES RIDGES	2	A 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	C 1	1	B 1	B 1	X	0	0	X	X	0	X
115 ICE TYPE	2	A 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	C 1	1	B 1	B 1	X	0	1	X	X	0	0
116 LOCATION OF SPRINGS	1	1	1	1	1	C 1	1	1	1	B 1	1	1	1	1	1	1	1	1	1	1	1	A 1	1	0	0	0	0	X	0	X	0	0
117 LOCATION OF GEOTHERMAL WATERS	1	1	1	1	1	C 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	A 1	B 1	0	0	0	0	X	0	X	0	0
118 AREA OF SWAMP	2	C 2	2	2	2	B 2	2	2	2	A 2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	X	X	X	X	X	X	X
119 AREA OF MARSH	2	C 2	2	2	2	B 2	2	2	2	A 2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	X	X	X	X	X	X	X
120 LOCATION OF GROUNDWATER	1	B 1	1	1	1	1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	C 1	1	0	0	0	0	X	0	X	1	0

*For B through E: 1 = vertical, 2 = oblique, 3 = strip, 4 = panoramic.
See Table I for Sensors. Letters over each column correspond to listing in Table I

10. **Explanatory Notes for Vegetation Elements (200 Series).**

a. **Evaluation of the 200 Series.**

201. FOREST STRUCTURE

(a) Definition: A physical description of a forest stand typically quantified by either the distribution of stem-diameter classes or stem-height classes per unit of area.

(b) Interpretation Variables: Detection of this MGI element is dependent on the density of the forest canopy or on the ability of the image interpreter to view the forest floor through the canopy. If a forest is multi-storied with one of the mid-stories maintaining a closed canopy, then all of the vegetation below this layer would be invisible to the interpreter. Since the age of trees cannot be determined remotely, stem diameter or height distribution is most often used to define the structure of a given forest. In general, an image scale of not less than 1:15,000 is required for the mid- to high-latitude forests with larger scales required in the more complex forests of the tropics.

(c) Remote Sensor Applications: Aerial photography (B1) has been the most used sensor in the past for determination of this element. Films and film/filter combinations that provide detail within shadow areas would, of course, supply more information. Microwave altimeters and laser profilers in combination with aerial photography should offer a more accurate and faster system for determination of stem or tree.

202. AREA OF FOREST TRACTS

(a) Definition: A determination of the area covered by a forest stand.

(b) Interpretation Variables: The advantages of measuring this MGI element from remote sensor imagery are obvious when this method is compared to the laborious ground method. Accuracy of this method depends on (1) scale of imagery, (2) topography, and (3) amount of tilt in aerial images. For relatively level terrain and imagery with less than 1^{o} tilt, accuracy within one-third of one percent has been reported. Recommended scales were not available in the literature in determination of this MGI element; however, scales larger than 1:40,000 should provide suitable accuracy levels.

(c) Remote Sensor Applications: Aerial photography (B1) has been the remote sensor most often used for the MGI element. Color and false color photography have proven to be of considerable aid in separating forest from other vegetation forms when stereo photography was not available. K-Band radar (L and M) imagery has also been used for this element, but accuracy levels are not available (Howard 1970).

203. CANOPY DENSITY[4]

(a) Definition: A computation of the percentage of ground area within a forest stand occupied by the vertical projection of the tree crowns (see Figure).

(b) Interpretation Variables: Canopy density is important for two reasons: (1) it is indicative of stem density; and (2) it could be used as a measure of the ability of a forest to conceal military objects. Crown closure or canopy density can be estimated on images ranging in scale from 1:7,000 to 1:20,000 with a standard error of estimate not greater than 10 percent (Spurr, 1960). Canopy density determinations of deciduous forests including some tropical forests have to be made when the crowns are in full leaf. In general, canopy density is overestimated from aerial photography and underestimated from ground observation.

(c) Remote Sensor Applications: The remote sensor requirements for this element are set by the definition of the term, i.e., the sensor must provide a near-vertical format. Aerial photography of types B1, C1, D1, and E1 are the types that were most often used in the past. Image scale should be no smaller than 1:20,000.

204. VEGETATION COLORATION (RELATIVE)

(a) Definition: A qualitative determination of the color of a plant community.

(b) Interpretation Variables: Based on available literature in the field of remote sensing, exact determination of this MGI element is not possible with the present state-of-the-art of remote sensing. Gourley, *et al.*, 1968, and Heller, 1964, have, however, reported methods for accurately describing the many color tones present on aerial color films of vegetation patterns, but the image colors may have little relation to the actual colors of the vegetation as they exist on the ground.

(c) Remote Sensor Application: Color emulsions and multiband imagery are the only remote sensors presently available to provide this information. When more data are available on the spectral response of the various plant species and associations, then airborne spectrophotometers may have more utility.

205. LOCATION OF FIRES

(a) Definition: A determination of the position and boundaries of a forest fire within a forest stand.

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[4] *Terminology of Forest Science, Technology Practice and Products*, 1971

(b) Interpretation Variables: The most opportune time to detect a forest fire is in its very early stages. At this stage of its life, the fire usually is small and located at or near ground level. Detection of a fire in these early stages is difficult both from the ground and from a remote platform. Forest canopy density, stem density, species composition, and season of year are all factors which can limit or affect detection of fires at an early stage of growth. Once a forest fire has reached sizable proportions, a constant need exists for instant information on the location of the fire boundaries and the number and location of "hot spots" within those boundaries.

(c) Remote Sensor Applications: Infrared thermal imagery (3 to 5) is able to provide enough information to locate not only the perimeter of a forest fire but also the more active fire areas within the perimeter. References are also available to document the use of this type of imagery to locate small fires scattered over a large forest tract.

Since the IR detectors perform so well and can provide the real-time information needed for location and extent of a fire, it is doubtful that other sensors will be used for detecting the MGI data element in the near future.

206. AREA OF CLEARINGS

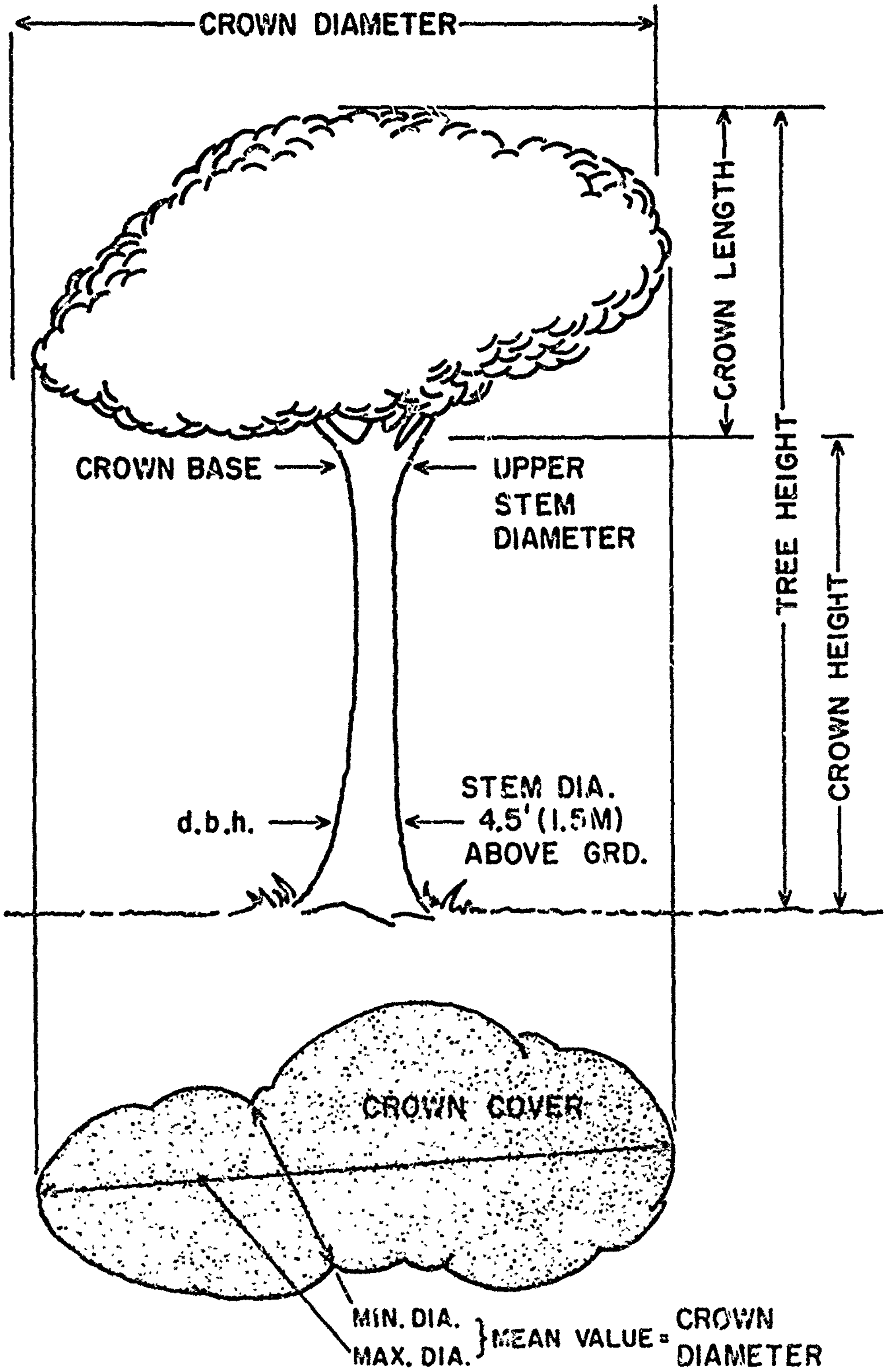
(a) Definition: A measurement of the areal extent of a clearing within a forest.

(b) Interpretation Variables: Detection of this MGI depends, primarily, on the scale and quality of the imagery. Recommended scales are not available in the literature for this element, but scales of 1:20,000 to 1:60,000 should provide accuracy levels suitable for most military operations.

(c) Remote Sensor Applications: As with most MGI elements concerned with vegetation, vertical aerial photography has been the major sensor used for collection of this type of data. As was stated above, the scale/size of clearing relationship has not been fully investigated with aerial photography nor with any of the more complex remote sensors. Detection and measurement of forest clearings should be possible by other sensors such as radar and thermal infrared.

207. TREE HEIGHT

(a) Definition: A determination of the height of a tree stem or bole measured from the ground-line/stem intersection to the highest point of the crown. In actual practice, it is usually either the tallest tree or the average tree height that is of importance to the military (see Figure on p. 63).



Tree measurement (*Terminology of Forest Science*).

(b) Interpretation Variables: Crown closure or canopy density, species composition of the forest, season of the year (deciduous forest), accuracy of image scale, and image quality are the major factors that affect determination of this MGI element. Forests with very dense canopies preclude visibility of the forest floor. However, such visibility is necessary for photogrammetric measurement of tree height. Coniferous forests and deciduous forests imaged during the non-leaf period are difficult to measure because of the non-resolution of the top portions of their crowns. The apparent similarity between elements 207 and 201 is explained by a difference in accuracy levels. MGI element 201 refers to canopy height—a more gross measurement than 207 (Tree Height).

(c) Remote Sensor Applications: Of the three types of photogrammetric methods available for the height determination, only the parallax method used by the U. S. Forest Service is considered accurate enough for MGI. Accuracies with this method vary with scale, but ±3-foot determinations have been reported on stereo photography imagery obtained at a scale of 1:6,000.

Other remote sensors that show promise for tree-height determination include radar, microwave altimeters, and laser profilers used in conjunction with either aerial photography or navigation position indicators.

208. TREE SPECIES

(a) Definition: A determination of the scientific name of individual trees within a forest.

(b) Interpretation Variables: Identification of tree species from remote sensor imagery depends on a number of factors which include: (1) scale and spectral response of imagery, (2) experience of image interpreter, (3) spectral signature of associated species, (4) ecologic range of species, (5) species diversity of forest, and (6) season of year. In general, species of mature trees endemic to areas of the world that maintain an extensive [illegible]ng or other forest product industries can be identified from remote sensor imagery. As an example, in the United States and Canada most of the economically important species can be identified from imagery. However, in the tropics where species composition of the forests are more complex, identification becomes more difficult, even on large-scale photographic imagery.

(c) Remote Sensor Applications: In the past, panchromatic and infrared panchromatic emulsions have been widely used for determination of this MGI element. In more recent years, color emulsions have become very popular and have proven to be more useful because less training is required for the image interpreter using this type film. Some work has been reported where radar (KA band) and thermal infrared have

been used for forest type or groups of associated species identification but not for separation of individual species. Photographic scales necessary for this MGI element vary from 1:2,400 to 1:15,000 depending upon species and experience or training level of interpreter.

209. TREE CROWN HEIGHT

(a) Definition: A determination of the distance between the stem/ground-line intersection and the first furcation or limb (see Figure on p. 63).

(b) Interpretation Variables: Direct measurement of this element from aerial imagery is not possible at the present time. The logging industry requires a somewhat similar measurement for wood volume determination (merchantable height), but it is determined from ground measurements.

(c) Remote Sensor Applications: As was stated in par. b, there is no direct method to determine this MGI element from remote sensor imagery. It is believed, however, that experienced image interpreters should be able to estimate this measurement from aerial photography obtained at scales of greater than 1:15,000 for certain species.

210. TREE STEM HABIT

(a) Definition: A determination of the growth form of an individual tree usually expressed as erect or multi-stemmed.

(b) Interpretation Variables: Determination of this MGI element depends primarily on image quality, species, and the structure of the forest community. Providing a qualitative description of the dominant plants of a community is usually not difficult on high-quality imagery obtained at a scale of 1:10,000 or greater. Determination of stem habit for sub-dominant species, however, offers a greater challenge and depends on the interpreter's ability to identify the dominant species in the forest community and then to supply the required data from his knowledge of the known species and its associate species.

(c) Remote Sensor Applications: In the past and for some time to come, vertical color (C1 and D1) and panchromatic aerial imagery (B1) will be the best sensors for this MGI element.

211. TREE STEM SPACING

(a) Definition: A determination of the mean distance between a tree and its nearest neighbor.

(b) Interpretation Variables: Tree-stem spacing can be determined from aerial imagery for those trees that form the canopy or emerge through the canopy. Subdominant trees and those stems growing beneath the canopy of the individual crowns of larger trees are not imaged and, therefore, cannot be measured. Multistoried forests common to the tropics provide the most difficult measurement conditions.

(c) Remote Sensor Applications: Aerial photography of types B1, C1, and D1 are the sensors most often used for determination of this data element. Image quality is probably more important than scale when establishing sensor requirements for determination of tree-stem spacing. Any emulsion that provides detail within shadow areas and that will resolve the tree crowns would be suitable. A scale of 1:20,000 or greater is recommended.

212. TREE CROWN DIAMETER

(a) Definition: A determination of the average diameter of a tree crown when viewed from a vertical position (see Figure on p. 63).

(b) Interpretation Variables: Determination of crown diameter from remote sensor imagery requires a number of simple distance measurements. The measurements are complicated, however, by the small size of the tree crown on the image, dense shadows caused by adjacent tree crowns, and the fact that in most canopies the complete crown is not visible. Crown diameter is one of the more important measurements since for most coniferous species and many hardwoods crown diameter is related directly to stem diameter and is the only method of obtaining stem diameter from R.S.I.

(c) Remote Sensor Applications: Aerial photography of types B1, C1, and D1 are the sensor types recommended for this element based on work done in the past. Photography obtained at a scale of 1:15,000 or larger should enable an interpreter to divide most forest types into 2-inch stem-diameter classes in areas when this relationship is known.

213. TREE CROWN LENGTH

(a) Definition: A measurement of the distance between the lowest branch of a tree crown and the upper terminus of the trunk or stem (see Figure on p. 63).

(b) Interpretation Variables: This MGI element is the complement of 209 (tree crown height). At the present time, a direct measurement of crown length from remote sensor imagery is not possible except in very open forest stands where measurements may be possible using the shadow of the tree. Oblique imagery of the margins of timber stands will not produce reliable results because tree crowns grown under these conditions are not representative of the crowns growing within the forest except for forests adjacent to recent clear-cut areas or wind-thrown areas.

(c) Remote Sensor Applications: Photographic remote sensors that provide dense black shadows would be suitable for this MGI data element. Sensor types B1, C1, and D1 obtained at a scale of 1:15,000 or greater would provide the most accurate information.

214. TREE BRANCHING HABIT

(a) Definition: A determination of the branching characteristics of a tree crown, i.e., horizontal or divergent.

(b) Interpretation Variables: The ability of an interpreter to separate individual tree crowns into the groupings listed in para. a is dependent on the following factors. type, scale, and quality of the image and also on the density, season of year, and species of tree. Fortunately, these two types of crown forms can be associated with two major groups of trees–coniferous and deciduous. Coniferous tree species normally have horizontal branching, while divergent branching is usually associated with deciduous species. Infrared color and panchromatic films provide a method of separating these major groups since the coniferous species are dark toned on the IR panchromatic and imaged as a deep red on IR color emulsion. While scales as small as 1.40,000 would be adequate, 1.20,000 would provide more reliable information on crown shape as well as branching form.

(c) Remote Sensor Application: Panchromatic infrared and color films of types D1 and E1 offer the most suitable means of determining this MGI element. At the present state-of-the-art, there appears to be no other sensors which could provide this data as well as aerial photography.

215. FOREST UNDERSTORY DENSITY

(a) Definition: A determination of the number of stems per unit of area in the understory of a forest. (An understory" is defined as any woody vegetation growing beneath the dominant and co-dominant trees in a forest.)

(b) **Interpretation Variables:** An exact measurement of the MGI element is not possible from aerial imagery at the present time. Understory density has been estimated from oblique photographs by an interpreter having a large amount of experience with actual ground conditions. Estimates of understory density have also been accomplished by measuring canopy density (element 203) and assigning a value based on a decrease in understory density with an increase in canopy density. However, both methods require image interpreters who are experienced not only with variations in plant communities but also with knowledge of forest conditions within the area of interest.

(c) **Remote Sensor Applications:** Vertical aerial photography with panchromatic film, unfiltered, at a scale of 1:10,000 or larger would probably be the best remote sensor for this MGI element over dense forests. In fairly open to open stands, aerial photography in conjunction with a laser profiler would provide enough information to determine understory density.

216. SHRUB STRUCTURE

(a) **Definition:** A determination of the physical composition of a shrub stand usually expressed as the distribution of stem height or diameter. (A "shrub" is defined as a woody plant 10 feet in height or under and is usually multi-stemmed.)

(b) **Interpretation Variables:** Measurements for determination of shrub structure from remote sensor imagery require methods similar to those used to determine forest structure (element 201). All of the factors affecting measurement of forest structure are also common to shrub structure with the additional need of large-scale imagery. The relationship between crown diameter and stem diameter for shrub species has not been developed as yet so exact determination of this MGI element from R.S.I. is not possible at this time. A number of studies have been reported in the literature on the use of R.S.I. for shrub height and density measurements (see element 217).

(c) **Remote Sensor Applications:** Aerial photography of types B1 through E1 has been the primary sensor for deriving this information in the past. Other sensors—radar, for example—have been tried but have not been successful because of resolution problems. Aerial photography obtained at the scales of 1:10,000 or greater is required for determination of this element.

217. SHRUB DENSITY

(a) **Definition:** A determination of the number of shrub stems per unit of area.

(b) **Interpretation Variables:** Measurement of shrub density from R.S.I is dependent on the quality, date, and scale of the imagery and also on the density and species

composition of the shrub stand. Shrub stands that are so dense that detection of individual crowns becomes difficult from ground inspection would be impossible to measure from R.S.I. Conversely, very small shrubs widely spaced may also be difficult to detect if such aids as their shadows are not used to enhance their location on the image. Measurement of the percent of area occupied by shrubs can be a more useful term than stems per unit of area.

(c) Remote Sensor Applications: As with most MGI data elements in the vegetation category, aerial photography of types B1, C1, D1, and E1 is most often used for detection of shrub density. Thermal infrared scanner imagery and radar have also been used, but resolution is often a problem with these types of sensors.

218. SHRUB SPECIES

(a) Definition: A determination of the specific or scientific name of a shrub.

(b) Interpretation Variables: Most of the problems associated with identification of tree species are also common with identification of shrub species. In the eastern forests of the U. S., for example, many shrub species can be classified by experienced interpreters using their knowledge of plant associations with known tree species and site requirements.

(c) Remote Sensor Applications: In general, aerial photography obtained at a scale of not less than 1:15,000 is suitable for remote sensor detection of this MGI element. Color emulsions should be considered superior to panchromatic films when interpreter experience of a particular location is either lacking or not well developed.

219. GRASS DENSITY

(a) Definition: A determination of the number of grass stems contained in a unit of area. When measured from R.S.I., this element is usually expressed as percent of area occupied by grass rather than actual number of stems per unit of area.

(b) Interpretation Variables: On large-scale, high-quality aerial photography, it is possible to determine grass density (Carneggie and Reppert, 1969). Accuracy of this information, of course, depends on the precision of the required photogrammetric measurements. An area grid template is usually employed as an aid to the interpreter in determining percent of land area occupied by grass.

(c) Remote Sensor Application: Aerial photography is the only sensor feasible for determination of grass density at the present time. Since color emulsion usually provides the greatest contrast between grass communities or between plant communities

and bare soil, it should be considered superior to panchromatic films for this MGI element. Recommended photographic scales vary from 1:600 to 1:1,500 for accurate determination of grass density.

220. GRASS SPECIES

(a) Definition: A determination of the scientific name of individual grass plants.

(b) Interpretation Variables: Determination of the specific names of the grasses is difficult and often requires close ground inspection of the plant with a hand lens. In many instances, positive identification can only be made when the plant is in the flower stage. (Most of the identification keys are developed around characterization of individual parts of the flower.) In recent years, however, successful species recognition has been accomplished using large-scale aerial color films of types C1 and D1. In most instances, identification of grass species depends on accurate ground truth and experienced interpreters with a knowledge of the plant associations endemic to the geographical area of interest.

(c) Remote Sensor Application: Vertical aerial color photography has been the most applicable sensor for this MGI element. Scales larger than 1:10,000 are required if the necessary ground truth is not available, i.e., vegetation map, ground photography, etc.

221. AREA OF AQUATIC VEGETATION TRACTS

(a) Definition: A measurement of the areal extent of aquatic vegetation.

(b) Interpretation Variables: Determination of the boundaries of an area of aquatic vegetation requires a remote sensor system that will provide maximum contrast between the vegetation and the water. In general, the infrared-sensitive emulsions (color and panchromatic) have this quality and have been successfully utilized for this purpose. Infrared sensitive color films would probably offer the maximum contrast with the vegetation varying from deep-red to red and the water, from dark-blue to blue. The recognition of the water/vegetation/land interfaces is often difficult but can usually be accomplished under stereo viewing. Aquatic species growing near the water surface are usually detectable with infrared color emulsions but will become more difficult or impossible to delineate in water with high turbidity.

(c) Remote Sensor Applications: Sensors of types C, D, F, and J are applicable for determination of this MGI element. While modes of imagery other than vertical could be used, near-vertical imagery would be more suitable. Infrared color vertical

photography obtained at scales of 1:10,000 or larger would provide the best sensor for measurement of this data element.

222. AQUATIC VEGETATION SPECIES

(a) Definition: Determination of the specific or scientific name of individual aquatic plants.

(b) Interpretation Variables: Aquatic plants vary in size according to species and length of growing season. In general, the portion of the plant visible to the interpreter may range from as small as 1/8 inch in diameter to several feet in diameter. Detection of aquatic plants depends, therefore, on size of plant or leaf area visible to the interpreter or, in the case of species growing entirely under water, leaf area, turbidity of the water, and depth below surface. In most instances, aquatic species form pure communities so that species recognition is not based on individual plant characteristics but rather on knowledge of habitat requirements, ground truth, and water depth.

(c) Remote Sensor Applications: Requirements for this element are similar to MGI element 221 with the exception of a need for a larger scale, especially with species that grow entirely underwater.

223. AQUATIC VEGETATION DENSITY

(a) Definition: Determination of the number of stems or plants per unit area of any species of aquatic vegetation.

(b) Interpretation Variables: Normally, there are two methods for quantifying this element: (1) by measuring the percent of an area occupied by aquatic vegetation; and (2) by counting the number of stems per unit of area. The first method yields a percentage quantity rather than a stem count; but, in many instances, this measurement is more useful and easier to obtain. The first method can also be employed using smaller scale and lower quality imagery than the stem-count method.

(c) Remote Sensing Applications: Color and false color emulsions are the most useful sensors for this element because they provide maximum contrast between the water and the vegetation. Scales as small as 1:40,000 can be employed, depending on the size of the aquatic species, for quantifying the MGI element.

224. CROP SPECIES

(a) Definition: A determination of the specific name of an agricultural crop.

(b) **Interpretation Variables:** Crop identification from R.S.I. is dependent on season of year, date of imagery, type and quality of imagery, and, to a certain extent, image scale. Of equal importance is a knowledge of the crops endemic to the area of interest. The interpreter knowing that the crop he is attempting to identify can only be one of a possible five species has a much easier task than if it were one crop out of a possible list of 20 species. The scale of the imagery necessary to determine crop species is difficult to define since many of the studies reported in the literature indicate that the tone and texture of the crop image was used for identification rather than the characteristics of the individual plant. With the availability of spectral-response curves for most crop species, selection of the remote-sensing system can now be based on the maximum separation between these curves at any frequency.

(c) **Remote Sensor Applications:** Color and false color films provide the most useful data for crop identification at the present time. Scales as small as 1:40,000 used with accurate ground data have been employed for crop identification. Multiband scanners have also been used and have been proven to be highly beneficial where the color films provide little tonal differences between two crop species. Radar can provide only broad classes of agricultural crops now; but, with more study and advances in radar technology, this sensor should be, in the future, the most useful sensor for this type of work at small scales and large area coverage.

225. CROP HEIGHT

(a) **Definition:** A determination of the vertical height of an agricultural crop.

(b) **Interpretation Variables:** Quantification of crop height requires methods similar to the measurement of grass height and is, essentially, a photogrammetric problem. The accuracy of these measurements depends on accurate ground control (vertical and horizontal), resolving power, and calibration of the R.S.I. system. The photogrammetric methods employed for tree-height determination are not considered adequate for crop height since measurement error of these methods is usually larger than the height of the average crop.

(c) **Remote Sensor Applications:** Photogrammetric measurements obtained from stereo vertical photography taken at scales of 1:10,000 with a cartographic camera should provide adequate data for measurement of crop height. This system, however, requires a complex ground-control net and first-order stereo plotting equipment. A laser profiler should be used for this type of measurement once this equipment has been perfected.

226. CROP PLANTING TIME

(a) Definition: A determination of the age of any given crop.

(b) Interpretation Variables: Direct determination of this MGI element from R.S.I. is, of course, impossible unless the imagery is obtained during the actual time of planting. Indirect determination should be possible, however, if enough inf· ·mation is known concerning the general agricultural practices of the area of interest. Local weather history and local custom determine the crop planting date more often than technical knowledge or information. The interpreter aware of local weath[illegible] nditions and crop types should be able to estimate crop planting date by measuring .op height at any time during the growing season. Another method of detecting the planting date could be provided by requiring sequential imagery of an area beginning in early spring and ending in early summer.

(c) Remote Sensor Applications: Aerial photography obtained at a sca[illegible] of 1:10,000 would provide suitable data to ascertain this MGI element if enough informa tion of local agricultural practices were available. This sensor system would also be ap plicable for detecting crop planting data by sequential photography.

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Table III. Vegetation Elements

MILITARY GEOGRAPHIC INFORMATION REMOTE SENSOR MATRIX	-	PANCHROMATIC				COLOR				COLOR IR				PAN IR				MULTI-BAND	NARROW BAND	TV	MULTI-SCANNER	IR SCANNER	MICROWAVE	RA RADARS	SA RADARS	GAMMA RAY	RADIOMETRIC SPECTROMETRIC	LASERS	MAGNETOMETRIC	GRAVIMETRIC	SPECIALIZED ELECTROMAG	PENETROMETER
*	A	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
201 FOREST STRUCTURE	1	B 1	1	1	1	A 1	1	1	1	C 1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	X	X	1	X	X	X	X
202 AREA OF FOREST TRACTS	2	A 2	2	2	2	C 2	2	2	2	2	2	2	2	B 2	2	2	2	2	2	2	[illegible]	2	2	2	2	X	X	X	X	X	X	X
203 CANOPY DENSITY	1	A 2	X	2	2	C 2	X	2	2	2	X	2	2	2	X	2	2	B 2	2	1	1	1	[illegible]	0	0	X	X	X	X	X	X	X
204 VEGETATION COLOR [illegible]	X	X	X	X	X	A 2	2	2	2	B 1	1	1	1	X	X	X	X	C 1	0	1	1	X	X	X	X	X	0	X	X	X	X	X
205 LOCATION OF FIRES	0	B 1	1	1	1	C 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	A 2	1	X	X	X	0	X	X	X	X	X
206 AREA OF CLEARINGS	2	A 2	2	2	2	C 2	2	2	2	C 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	X	X	X	X	X	X	X
207 TREE HEIGHT	2	A 2	1	2	2	B 2	1	2	2	C 2	1	2	2	2	1	2	2	2	2	X	X	X	X	X	X	X	X	1	X	X	X	X
208 TREE SPECIES	1	1	[illegible]	1	1	A 1	1	1	1	1	1	1	1	C 1	1	1	1	B 1	1	0	1	1	1	0	0	X	1	X	X	X	X	X
209 TREE CROWN HEIGHT	0	B 1	0	0	0	A 1	0	0	0	1	0	0	0	C 1	0	0	0	1	1	0	0	0	0	0	0	X	X	0	X	X	X	X
210 TREE STEM HEIGHT	1	A 1	0	1	1	B 1	1	1	1	1	1	1	1	1	1	1	1	C 1	1	0	0	1	1	0	0	X	X	X	X	X	X	X
211 TREE STEM SPACING	1	A 2	0	2	2	B 2	0	2	2	C 2	0	2	2	2	0	2	2	2	2	0	0	1	1	X	X	X	X	1	X	X	X	X
212 TREE CROWN DIAMETER	2	C 2	0	2	2	A 2	0	2	2	B 2	0	2	2	2	0	2	2	2	2	0	0	1	1	X	X	X	X	0	X	X	X	X
213 TREE CROWN LENGTH	0	A 1	0	1	1	B 1	0	1	1	C 1	0	1	1	1	0	1	1	1	1	0	0	1	1	X	X	X	X	0	X	X	X	X
214 TREE BRANCHING HABIT	2	A 2	2	2	2	B 2	2	2	2	C 2	2	2	2	2	2	2	2	2	2	0	0	2	1	X	X	X	X	X	X	X	X	X
215 FOREST UNDERSTORY DENSITY	1	A 1	1	1	1	B 1	1	1	1	C 1	1	1	1	1	1	1	1	1	1	0	0	1	1	X	X	X	X	0	X	X	X	X
216 SHRUB STRUCTURE	1	B 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	C [illegible]	1	0	0	0	0	0	0	X	X	1	X	X	X	X
217 SHRUB DENSITY	1	A 2	1	2	2	B 2	1	2	2	C 2	[illegible]	2	2	2	1	2	2	1	1	0	0	0	0	0	0	X	X	1	X	X	X	X
218 SHRUB SPECIES	[illegible]	C 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	B 1	1	0	0	[illegible]	0	0	0	X	0	X	X	X	X	X
219 GRASS DENSITY	1	A [illegible]	1	2	2	B 2	1	2	2	2	X	2	2	2	1	2	2	C 2	2	0	0	0	1	0	0	X	X	1	X	X	X	X
220 GRASS SPECIES	1	B 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	C 1	1	0	1	1	0	0	0	X	X	0	X	X	X	X

*For B through E 1 = vertical 2 = oblique, 3 = strip, 4 = panoramic.
See Table I for Sensors. Letters over each column correspond to listing in Table I

Table III (cont'd)

	*	PANCHROMATIC				COLOR				COLOR IR				PAN IR				MULTI-BAND	NARROW BAND	T.V.	MULTI-SCANNER	IR SCANNER	MICROWAVE	RA RADARS	SA RADARS	GAMMA RAY	RADIOMETRIC-SPECTROMETRIC	LASERS	MAGNETOMETRIC	GRAVIMETRIC	SPECIALIZED ELECTRONIC	PENETROMETER
	A	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
221 AREA OF AQUATIC VEGETATION TRACTS	0	2	2	2	2	2	2	2	2	B 2	2	2	2	A 2	2	2	2	2	2	2	C 2	2	2	1	1	X	X	X	X	X	X	X
222 AQUATIC VEGETATION SPECIES	0	1	1	1	1	B 1	1	1	1	A 1	1	1	1	1	1	1	1	C 1	1	1	1	1	0	0	0	X	0	X	X	X	X	X
223 AQUATIC VEGETATION DENSITY	0	1	1	1	1	B 1	1	1	1	A 1	1	1	1	C 1	1	1	1	1	1	1	0	1	1	0	0	X	0	1	X	X	X	X
224 CROP SPECIES	0	B 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	C 1	1	1	1	1	0	0	0	X	0	X	X	X	X	X
225 CROP HEIGHT	0	A 1	1	1	1	B 1	1	1	1	C 1	1	1	1	1	1	1	1	1	1	0	0	X	0	0	0	X	X	1	X	X	X	X
226 CROP PLANTING TIME	0	C 1	1	1	1	B 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	X	0	1	X	X	X	X

* For B through E 1 = vertical 2 = oblique, 3 = strip 4 = panoramic
See Table I for Sensors. Letters over each column correspond to listing in Table I

11. Explanatory Notes for Landforms and Surficial Materials Elements (300 Series).

a. Evaluation of the 300 Series.

301. TYPE OF SURFICIAL DEPOSIT

(a) Definition: A determination of the type of surficial deposit based on origin, occurrence, and environmental setting.

(b) Interpretation Variables: This discussion will emphasize the type identification, through recognition of primary characteristics, of the unconsolidated surficial materials, or deposits, overlying the bedrock of a region. Surficial geology is a term sometimes used for these deposits as opposed to bedrock geology which deals primarily with the consolidated rocks and sediments of the upper part of the earth's crust. The properties of these bedrock units, where the bedrock is exposed in outcrops, can be determined and the rock type can be identified in much the same manner as surface deposits are identified. The bedrock units have distinct properties and outcrop expression. Bedrock units are the parent materials from which the surface deposits were originally derived. This relationship is most apparent for deposits formed in place. The surface deposits have accumulated and undergone change through the action of various geologic processes, and they occur in association with (or comprise) characteristic landforms such as floodplains, terraces, alluvial fans, glacial moraines, etc.

Geologically, surface deposits are classified and their distributions mapped according to similarity of physical properties and relation to landforms with some attention paid to origin and genetic relationships. Engineering soils classifications are applied to surface deposits largely on a physical basis with parameters such as size distribution, clay content, and engineering behavior of the materials emphasized. Genetic relationships are not considered. These engineering properties can be determined directly on the ground by sampling, or they can be estimated (or predicted) using various types of sensor imagery. The remote determination of properties of surficial deposits can be made with greater assurance if the type of deposit can be positively identified. Based on knowledge of the probable origin and characteristics common to a particular type of deposit, additional inferences can be made on such properties as texture, composition, probable depth (if not directly observable), etc. These inferences will be made with regard to possible modifications in properties brought about by the environmental setting in which the deposit occurs.

This discussion of surface materials and deposits does not include soils determinations in the agricultural or pedological sense. Such soils classifications are concerned primarily with those surface and near-surface horizons developed in earth

materials where vigorous biological activity occurs and where rooted plants are supported. Pedological soils classifications do, however, include considerations of morphology and landform association. Surficial deposits derived from bedrock units can be formed in place under the influence of various physical and chemical processes, or they can result from erosion and subsequent deposition by various transporting agents such as wind, water, ice, and gravity–or combinations of these. Transport can occur over short distances only, as in the case of slope colluvium, or transport may be over great distances as in the case of some loess deposits. Primary relationships between a deposit and its source area are generally more evident where transport distances are of small magnitude. The resultant deposit, either a landform in its own right or associated with a distinct landform, has certain characteristics which indicate its primary mode of origin. Sand dunes, for instance, accumulate under the influence of winds; glacial eskers and outwash deposits are products of glaciers and meltwater from glaciers.

Numerous clues are used to initially discriminate and subsequently identify a deposit and to determine its properties from remote sensor imagery. These include color (or grey tone), size and shape of deposit, vegetation associations, drainage development, topographic setting and relation to landforms, cultural utilization, etc. Clues to the subsurface are looked for in cuts and gullies, and their attributes and angles of repose are noted. From empirical knowledge, the type identification of a deposit allows further interpretive judgments to be made which are not directly discernible. Such associations provide the basis for inductive and deductive reasoning within one or several disciplines. As a simple example, active sand dunes are generally composed of subangular to rounded grains of resistant materials such as quartz and have a characteristic grain-size distribution, porosity, permeability, etc. The dunes are generally poorly consolidated and have characteristic shapes and slope angles.

Many other probable inferences can be made about the dune deposit with varying degrees of reliability. The making of mutually compatible primary and secondary judgments from various lines of direct and indirect evidence is all part of the interpretive procedure–the method of extracting information from remote sensor imagery. Much of the success and accuracy of the interpretation necessarily depends on the skill, background, and interest of the interpreter (or interpreters).

The interpretive procedure for extracting information from aerial imagery is outlined in many publications (Frost, *et al.*, 1953; Lueder, 1959; American Society of Photogrammetry, 1960). The techniques were largely developed for aerial photography but can be adapted to other forms of remote sensor imagery. In general, the terrain-oriented procedures include a regional-to-local approach in which the pattern elements of the landscape–the physical, biological, and cultural components are analyzed and related together in order to obtain meaningful information. These interpretive techniques when used for analyzing imagery other than photography must consider the

unique energy forms and special operating characteristics of the sensing systems involved.

The characteristics of common landforms and associated deposits are discussed in a variety of geologic and geographic tests. For example, Thornbury (1954) presents a classical overview of the field of geomorphology; and Flint (1971) gives a comprehensive treatment on glacial and periglacial landforms, deposits, and processes.

(c) Remote Sensor Applications: Aerial photography continues to be the most widely used type of remote sensor imagery for deriving information on the physical, biological, and cultural components of the earth's surface. Panchromatic films continue to be widely used, but other film types are increasingly utilized such as UV, black and white IR, color, and color IR. Various film/filter combinations have been shown to be valuable for deriving information on terrain and materials, and, for some special and general investigations, increasing use is made of film/filter combinations in special, multiple-camera setups. These provide simultaneous coverage across the entire visible and near-visible spectrum or discrete segments. Electro-optical scanning devices have been developed to provide similar coverage; the signal data from these sensors are more amenable to electronic data processing techniques but the imagery usually lacks the unitary geometry of frame photography. In an effort to develop discriminatory signature data, work has been done on investigating the reflectance characteristics of surface materials in different environments and under various atmospheric conditions.

Improvements in color films (speed, graininess, etc.) and processing techniques (rapid and controlled developing and reproduction) combined with narrowing cost margins have helped to stimulate a wider general use of color films. Numerous articles have appeared in the literature on the merits of color and color IR films for deriving information on earth materials, for general investigations of physical, biological, and culture phenomena, and for photogrammetric mapping (Reed and Rinker, 1968; Anson, 1968; American Society of Photogrammetry, 1968). These films are widely utilized because of their generally high information content and ease of interpretation. Positive transparencies apparently allow maximum discrimination of detail. Critical factors such as sunlight, exposure, and color balance which should be considered for optimizing the results of special color photo missions are outlined by Hunter and Bird (1970).

Although not in common use, ultraviolet photography can be uniquely utilized for detecting and identifying certain types of materials such as evaporites and carbonates which characteristically have high reflectances in the UV. Experimental use has also been made of a high-resolution grating spectrometer for identifying various luminescent materials under natural sunlight conditions. Active UV systems (cathode ray tubes, mercury vapor lamps, and UV lasers) which stimulate luminescence in certain minerals and rocks such as talc and dolomite have also been experimented with

(Hemphill, 1968). Unique response characteristics can hopefully be used as a means for identification.

Thermal infrared scanner imagery may be useful for discriminating between surface materials and deposits not readily differentiable on other forms of imagery. Differences in materials, either inherent or environmentally influenced, may give rise to distinct thermal signatures which can serve as a basis for discrimination and identification. Ideally, thermal imagery allows differentiation between bedrock and unconsolidated deposits, between various deposits, and between different bedrock types. Depending on a number of factors, signal contrast may be greatest either for daylight or nighttime imagery for a particular range of bedrock and deposit types.

The moisture content of surface deposits greatly affects their thermal response. Thermal signatures caused by anomalous moisture conditions can give rise to erroneous conclusions, but if moisture differences are inherently the result of natural properties—sands versus clays, for instance - then a solid basis for differentiation exists. Other environmental effects such as local temperature inversions can also give rise to anomalous signals and must be allowed for. Thermal IR and also passive microwave imagery can be a valuable supplement to more conventional imagery. A greater depth of information is sometimes gained by using a combination of sensors. An example of a multisensor approach to a problem is given by Orr and Quick (1971).

Radar imagery, SLAR especially, can be used for evaluating surficial deposits but, because of small scale and limited resolution, only on a broad, general basis. The same interpretive procedures used for extracting information from photography can be applied to radar imagery with some necessary modifications. The radar image is a specialized presentation of the landscape lacking the detailed information content of a photograph; however, unique detection can occur as a result of radar energy/matter interactions, and specialized data can be generated. With radar imagery, the broader patterns of landform, rock, drainage, vegetation, and land use can be used effectively to generate data on the general type, distribution, and relative thickness of surficial deposits. Some inferences can also be made on composition and texture of surficial deposits. Radar imagery is especially useful in the initial stages of regional investigations to outline gross features and distributions of surface materials and, for some purposes, is totally adequate by itself. Radar imagery can also be obtained at night and under atmospheric conditions that would prohibit the acquisition of photography.

The radar scatterometer, which monitors the reflective response of earth materials—a function of frequency and look angle - can also be used for discriminating and identifying these materials.

Airborne gamma-ray sensors have use for differentiating between and mapping distributions of certain types of surficial materials as well as bedrock. The radioactive elements uranium and thorium and their daughter by-products, and also potassium-40, are widely present in surficial materials and sediments in general. The quantity of these elements in sediments (hence intensity of radiation) varies as the result of a number of factors which include lithology, age, and weathering and erosive history (geologic history) of the sediments. These factors combine uniquely to give some sediments a particular radioactive signature which can be used as a means of differentiation. Gamma-ray techniques can also be used to map distributions of certain types of subsurface bedrock under residual soils and, in some cases, to trace sediments back to source areas.

Air-droppable earth penetrometers are capable of yielding useful data on properties of surface and near-surface materials and, also, data on thickness, layering, and depth to bedrock for relatively shallow deposits. The data, however, is generated from the point of impact only and must be interpolated when applied to the immediate surroundings. The penetrometer can serve as a useful supplementary sensor to conventional imagery.

302. COMPOSITION OF SURFICIAL DEPOSIT

(a) **Definition:** A determination of the gross mineralogical composition of surficial deposits.

(b) **Interpretation Variables:** The composition of a surficial deposit can refer to the actual mineral or rock-type makeup of the component particles (minerals such as quartz, feldspar, and magnetite; rock types such as granite and basalt) or to the overall size distribution of the component particles. Surficial deposits can be classified on the basis of particle size distribution and terms such as gravel, sand, silt, and clay to denote certain particle size designations. Such physical classifications are useful and a number of engineering properties are predictable based on particle-size classification alone. Element 306 (Texture of Surficial Deposit) treats the subject of particle size distribution specifically.

The remainder of this discussion will treat mineral or rock-type composition only. The determination of the composition of surficial deposits from remote sensor imagery is done largely through interpretive procedures in which numerous clues are used to infer composition and other properties. The identification of a deposit as to type allows many subsequent judgments to be made. This general subject is treated in depth under element 301 (Type of Surficial Deposit).

(c) **Remote Sensor Applications:** Many different types of sensor imagery can be used to obtain information on mineral and rock-type composition of surface deposits.

The general merits and limitations of various remote sensors in this regard are discussed under element 301 including examples of interpretive procedure. Photography, particularly color and color IR, probably offers the best single means of remotely deriving information on composition.

Special sensors such as magnetometers and gamma-ray spectrometers are capable of directly sensing special properties (magnetic susceptibility, radioactive nature) of materials comprising certain deposits, and such information may be of use in making broad inferences on composition.

303. AREA OF SURFICIAL DEPOSIT

(a) Definition: A determination of the area of distribution of surface deposit.

(b) Interpretation Variables: There are necessary steps in the interpretive procedure that must be completed before the area of any feature can be determined from aerial imagery. The feature must first be detected, recognized, or identified, and bounded. The identification of surface deposits has been discussed under element 301. Determining the exact boundaries of a deposit can be as difficult as identifying it.

Once the deposit is outlined, its aerial distribution can be determined. This can be done on a variety of remote sensor imageries of appropriate quality, scale, and metric fidelity. Area can be estimated or measured with simple desk-type instruments or complex mensuration equipment. The procedures for these operations are outlined in a number of texts and manuals. Presuming that the boundaries of a deposit have been previously determined, the level of skill needed by an operator depends on the type of imagery used, the measurement techniques employed, and the accuracy required.

Accurate horizontal measurements needed for area determinations require that the imagery has good two-dimensional fidelity. Area determinations are possible from many types of remote sensor imagery, although accuracy will vary since the inherent geometry and resolution of imagery varies with the different sensor systems. Nonstereo imagery can generally be used for area determinations, but stereo is always desirable as it increases ease and accuracy of measurement.

The geometry of remote sensor imagery is, in general, simple for most types of aerial photography and more complex for other imaging sensor systems. Photography provides the best overall resolution. The geometry and resolution capabilities of various types of remote sensor imagery are discussed in many articles, texts, and manuals some of which are listed as references in paragraph 11b.

(c) **Remote Sensor Application:** Aerial photography, especially vertical photography, is probably the most widely used imagery for area determinations of surface deposits and also for many other features. Various film types are used to obtain maximum information content and to increase ease of interpretability and measurement. The geometry of vertical photography is relatively simple (assuming no appreciable distortion from topographic relief and attitude of the aircraft platform). Measurements can be made along all azimuths. Distortion increases from the principal point of the photograph radially outward toward the edges, but this can be easily corrected. Geometry is more complex for other photographic formats such as oblique and panoramic; panoramic photography is especially a problem. Orthophotos of sufficient quality and resolution can also provide an excellent means for determining areas of surface deposits.

Area determinations can also be made from other types of remote sensor imagery. Television images can have good geometric fidelity and resolution. Imagery from line-scanning thermal IR and passive microwave systems can be used for general area determinations, but spatial resolution is much poorer than photography (especially with microwave). In addition, there are many internal and external factors that can adversely affect the quality of scanner imagery; image geometry is complex and rectification techniques are involved.

Areas of surface deposits can be determined from radar imagery. The geometry of radar imagery, including SLAR, allows relatively accurate horizontal measurements to be made; however, the general small scale, limited resolution, and tonal contrast make the use of radar imagery practical only for large, well-defined deposits.

The laser profiler has little direct application for determining areas of surface deposits since it provides only line-trace data. As an accurate altimeter, however, it can provide the means for calculating exact scale for supplemental photography. A scanning laser, if developed, would be useful for making accurate determinations of area

304. THICKNESS OF SURFICIAL DEPOSIT

(a) **Definition:** A determination of the depth of surface deposits.

(b) **Interpretation Variables:** This discussion will be largely confined to thickness determinations of surface deposits, such as floodplain and glacial-till deposits, which are formed by distinct processes and are associated with distinct landforms. This is in keeping with the spirit of the discussion presented in element 301 (Type of Surficial Deposit).

The earth material penetrating capability of the more conventional remote sensors such as infrared and microwave scanners and radar is generally limited to a few

feet. Water and its frozen phase, ice, are exceptional materials being relatively homogeneous and transparent to electromagnetic and acoustical energy at certain frequencies. Deep penetration and thickness determinations can be made with several surface-based and airborne sensors. Some of the sensors and techniques used for determining water depth are discussed in element 101. The subject of thickness determination of floating ice is discussed in element 113. Glaciers and ice caps are discussed in element 310; specialized radar techniques have been used to sound ice caps several thousand feet in thickness.

In general, the more conventional airborne remote sensors, both active and passive, sense earth surface and very-near earth-surface phenomena only. Deeper phenomena may be detected but, largely, through secondary effects detectable at the surface. Most of the data on subsurface properties and thicknesses of earth materials derived from conventional remote sensor imagery is inferred through interpretive techniques. The data on surface phenomena are used to extend the interpretive judgments to the subsurface. Direct determinations of subsurface properties and thicknesses can sometimes be made where large exposures exist or where smaller "windows" to the subsurface occur in the form of erosional gullies.

Interpretive procedures for determining subsurface properties and thicknesses of surface deposits rely heavily on identification of the type of deposit. Certain deposits are characteristically associated with unique landforms and are the products of selective processes of weathering, erosion, and transport (wind, water, ice, gravity, or combinations of these). These deposits have characteristics which are predictable to a certain extent. Once a deposit is identified as to type and origin, generalizations can be made about its properties, distribution, and probable thickness. Numerous other clues can also be used to indicate the thickness of a deposit or to make generalizations about depth to bedrock, etc. This general subject is treated more extensively in element 301 (Type of Surficial Deposit).

There are several ground-based sensing techniques for deriving information directly on subsurface properties and distribution and thickness of earth materials. Ground-based shallow seismic and electrical resistivity techniques utilizing artificial energy sources are capable of good definition of surface and near-surface deposits. The shallow seismic technique utilizes a shock device (explosive, hammer blow, etc.) and an array of geophones to determine material type, layering, and overall thickness of a deposit by monitoring the rate of travel of the shock wave and the modifications caused by reflection and refraction. The shallow-resistivity technique utilizes active electrical probes and a monitoring device to determine material properties, layering, and overall thickness by measuring the electrical conductivity. There is an extensive literature on the use of these shallow geophysical techniques. They can be used in conjunction with

airborne sensor techniques to provide complementary data for such projects as highway route selection (Mayhew, 1964).

Remote sensing from airborne platforms necessarily eliminates some types of ground-based sensing techniques and forces modifications in the use of others. Active seismic techniques would be largely restricted to the dropping of explosive devices and appropriate monitoring sensors. Active airborne resistivity techniques would require appropriately large antennae, etc., mounted to the aircraft. Such specialized airborne sensing techniques are discussed later in this presentation.

(c) Remote Sensor Applications: Aerial photography is commonly used for interpretive investigations of surface earth materials. Photography is capable of excellent definition, is versatile, and is easily obtained. It can be used for making estimates of the thickness of deposits through interpretive techniques or for obtaining direct thickness measurements where exposures permit. Vertical stereo photography would offer the simplest geometry and panchromatic films, the widest latitude of exposure, greatest economy, etc. Color and color IR films, however, would generally be the most useful films for making thickness determinations since the identification of deposits and discrimination of boundaries would be easier to make. The actual choice of film for a specific use, however, depends on a number of factors such as the nature, location, and general environment of surface deposits, meteorological conditions, etc. Multiple photo coverage of an area may be desirable using a variety of film/filter combinations to permit maximum discrimination. Other remote sensors may have to be used in conjunction with photography to obtain comprehensive data.

Aerial photography (vertical and oblique formats) has been used with good results to obtain snow thickness data over courses where vertical, graduated markers have been set up (Finnegan, 1962). In the absence of established markers, estimates of snow thickness can be made using fence posts, etc., as height references.

Imagery from other types of remote sensors such as television, visible spectrum scanners, thermal IR scanners, etc., also have use for making thickness determinations insofar as the imagery can be used for discriminating and identifying surface and near-surface deposits and their properties. Some direct measurements of surface exposures are also possible. The factors limiting the usefulness of some of the non-photographic sensor imagery include lack of routine stereo coverage, restricted resolution, and complex and variable geometry. The geometry of various types of remote sensor imagery in relation to area and elevation determinations is discussed in elements 303 and 313.

Some subsurface features and deposits (caves, water-bearing gravels, etc.) may be uniquely detectable on thermal IR and passive microwave imagery to the extent that they produce (directly or through secondary effects) distinct thermal signatures at

the surface. The detection of such signatures and recognition of their significance, however, give no direct determination of depth of occurrence or thickness of the subsurface feature or deposit, although depths will generally be shallow.

Radar imagery, particularly SLAR, has use for making thickness determinations but, because of generally small scale and limited resolution, only on a broad basis. Radar uniquely portrays the landscape (topography, structure, drainage, etc.) in stark detail, and provides clues, which can lead to information on properties of surficial materials, in the form of gross textures and tones. The discrimination of materials and their distribution in relation to topography allow some genetic identification of deposits and associated landforms from which interpretive judgments may be made on probable thickness, depth to bedrock, etc., as previously discussed. See article by Holmes (1967).

Specialized radar systems also offer promise of directly obtaining subsurface data on earth materials. Lundien (1971) reports on the experimental use of swept-frequency radar for determining depths and layering in subsurface materials.

The air-droppable penetrometer is a specialized remote sensor (in less than the strict sense) which is capable of directly penetrating earth materials to limited depths (depending on size, etc.) and telemetering data on properties and depth based on rate of deceleration. The penetrometer has been shown to be a useful sensor for making determinations on layering, depth to bedrock, and on the general nature of materials penetrated (Marien, 1970). It has also proven highly accurate for determining sea-ice thickness. It is limited in that it generates point data only, and the data must be interpolated over a wide area from the point of impact. Supplementary remote sensor imagery could be used for this purpose. Development of a low-cost disposable penetrometer would greatly increase its usefulness.

Such airborne geophysical sensors as magnetometers (which determine magnetic susceptibility) and gravimeters (which determine variations in density) are used for relatively deep probing, on a broad scale, of earth materials. Magnetometers have special use for locating mineral deposits and determining rock type and can provide some general data on depth to bedrock. Gravimeters have general use for determining rock type, shape of intrusive bodies, extent of sedimentary basins, etc.

Two specialized airborne systems for detecting subsurface features and deposits are described by Barringer and McNeil (1969, 1971). The first of these, the Induced Pulse Transient System (INPUT), has been used for some time in mineral exploration. A large coil mounted below an aircraft is used to generate earth-penetrating pulses of electromagnetic energy which are monitored, and the electrical conductivity of the underlying terrain is thus determined. The system is highly sensitive to local conductive bodies and is capable of detecting ore bodies at depth (several hundred feet).

The system apparently has a general capability for differentiating gravel deposits, clays, and clay-rich soils and for providing information on layering, depth to bedrock, depth to water table, etc.

The E-Phase™ is a relatively new system which utilizes radio frequency energy from VLF and commercial broadcast stations to obtain information on subsurface terrain. Ground waves which penetrate deeply into the earth's surface are propagated from these stations for great distances. These signals are monitored by the E-Phase™ system. Signal behavior is largely a function of the electrical conductivity of subsurface earth materials and can be translated into meaningful geologic data. The system is apparently capable of providing some information on regional structural features and on local deposits such as gravels, permafrost, depth to bedrock, and depth to water table. Experimental use of the E-Phase™ system has indicated that the broadcast bands provide penetration depths varying between 10 to 100 feet versus 50 to 500 feet for the VLF.

305. COLOR (RELATIVE) OF SURFICIAL DEPOSIT

(a) Definition: A determination of the relative color of surficial deposits.

(b) Interpretation Variables: Color, although a variable property, is important for identifying surface deposits since it contributes information to the convergent logic used in the identification procedure. Many factors affect the apparent color of surficial deposits and the determination of color by remote means. Among these factors, moisture content and quality and quantity of illumination or sunlight are especially important. Because these and other related factors are variable and because of inherent limitations in remote sensing systems, color determinations by remote means are relative only and are not exact. However, some forms of remote sensor imagery can approximate the apparent visual color of materials. The human visual apparatus, limited in sensitivity to a small portion of the electromagnetic spectrum, also senses color but only approximately. Certain types of color imagery are thus adequate for remote sensing investigations and interpretations since the landscape is represented in colors closely related to the human visual experience.

(c) Remote Sensor Applications: Color photography is capable of approximating the apparent color of surface deposits. Color representation will necessarily vary with different film types and environmental conditions. Good relative color representation is also possible with special electro-optical imaging systems such as television. Rib (1968) gives a comprehensive treatment of the various descriptive, physical, psychological, and psychophysical systems used for designating color.

306. TEXTURE OF SURFICIAL DEPOSIT

(a) **Definition:** A determination of the geometrical aspects of the component particles of a surface deposit including size, shape, and arrangement.

(b) **Interpretation Variables:** The above definition can be applied both to bedrocks and to materials comprising unconsolidated surface deposits (or "soils" in the engineering sense). The emphasis is usually on the size distribution of the component particles. In general descriptions of surface deposits, or soils, broad terms such as "fine grained" or "coarse grained" can be used. Surface deposits can be more exactly classified according to size distribution of component materials; examples of size terms are gravel, sand, silt, and clay as used in the Unified Soil Classification System. Appropriate modifiers can be used for each major size category such as silty sand if a sand contains an appreciable amount of silt. Clays are also described in terms of the degree of plasticity exhibited. Classifications also usually include entries describing organic-matter content if present in significant amounts.

(c) **Remote Sensor Applications:** Determinations of texture of surface deposits can be made from a variety of remote sensor imagery. Most of the information is derived or inferred through interpretive techniques. These techniques and procedures are described in detail under element 301 (Type of Surficial Deposit). Generally, photography offers the best means for making determinations of texture.

307. MOISTURE CONTENT OF SURFICIAL DEPOSIT

(a) **Definition:** A determination of soil moisture content generally expressed in relative terms.

(b) **Interpretation Variables:** The moisture content of surficial deposits (or "soils" in the engineering sense) can vary greatly over a given area and also, with time. Thus, soil moisture determinations even when made by ground methods are valid only for limited areas and for limited time periods. Especially affected is the surface or air-soil interface which can dry quickly even after extensive wetting. Such dry surfaces can be misleading since appreciable moisture may be present in the subsurface, especially in clays or clay-rich soils. Since most remote sensing systems sense surface phenomena only, determinations of subsurface moisture can be difficult.

The moisture content of surficial materials at any given time depends on many interrelated factors among which are the type of material or soil, topographic setting, and availability of moisture. The moisture supply can be in the form of rain or other type of precipitation, surface runoff from surrounding areas, groundwater inflow, etc. Minor periodic wetting can occur from condensation phenomena such as dew. As

an example of the interrelationships of the above factors, different surface materials such as sands and clays occurring in the same topographic setting and under similar conditions of moisture supply will probably have different moisture contents because of textural differences, etc. Conversely, similar soils in dissimilar topographic settings may have different moisture contents because of variations in moisture supply, drainage conditions, etc. Factors and relationships such as these have to be kept in mind when evaluating moisture conditions of surface materials from remote sensor imagery.

Various types of remote sensor imagery can be used to evaluate moisture conditions of surface deposits. An interpreter uses many direct and indirect clues to make inferences on moisture conditions. Photographic tones, for instance, can be used as more or less direct indicators of moisture levels, within limits, since moisture tends to darken the natural colors of deposits. Vegetation associations, cultural modifications of the landscape, crop types (and vigor), etc., are more indirect indicators of general moisture conditions in surface deposits as are springs, seeps, and standing water bodies. A regional-to-local approach as outlined under category 120 (Location of Groundwater) is advocated for making general evaluations of moisture conditions in an area. With this approach, all aspects of the landscape such as those outlined above, and including topography and drainage, are used in evaluating general moisture conditions and for making inferences on moisture conditions of specific surface deposits.

Whatever the remote sensor system employed or the interpretive techniques used, however, determinations made on moisture conditions, for the most part, will be relative in nature. Statements will be made on the general wetness or dryness of surface deposits, or general estimates will be made on moisture content using such terms as low, medium, or high moisture content. More explicit statements can sometimes be made under special circumstances. The state of the art of remote sensing as related to moisture content of surficial deposits is such that only relative determinations are possible.

In recent years, however, work has been directed toward developing more quantitative techniques for determining the moisture content of surficial deposits. Good results have been obtained for test areas where periodic sensing missions have been flown and ground and atmospheric conditions closely monitored (Schmer, *et al.*, 1970). This empirical approach has resulted in the establishment of definitive relationships for specific test sites which enable moisture conditions to be determined from remote sensor data obtained at select times and under select meteorological conditions. Work also continues on ground-based tests and laboratory investigations on the effect of moisture on the reflectance characteristics and thermal properties, etc., of surficial earth materials. Such combined programs offer promise for the development of quantitative techniques for the remote determination of moisture content in surficial deposits under a variety of environmental conditions.

(c) **Remote Sensor Applications:** Photography has wide application for investigating moisture conditions of surficial deposits and for water resources investigation in general. Aerial photography allows an interpreter to view the landscape as it would appear naturally from the air (especially true for color photography) and to study in detail the various components of the landscape that give clues as to general moisture conditions. These components include topography and landforms, surficial deposits, natural and artificial drainage channels and water bodies, vegetation assemblages, and landuse patterns. Photographic tones can also be used as general indicators of moisture conditions or for more specific determinations such as may be obtained by densitometric analysis of photography acquired over calibrated test sites.

Infrared-sensitive films would probably offer the greatest benefits for determining moisture conditions in surficial deposits since there is high absorptance of infrared radiation by moisture. Color IR films would also offer greater ease of recognition of important supplemental indicators such as vegetation assemblages, drainage, and cultural features.

Multiband systems, using various film/filter combinations or selective segments of the expanded visible-light spectrum, are useful for obtaining information on moisture conditions of surficial deposits. Use of select narrow bands, especially over test areas, shows promise for obtaining reliable data on moisture content. Application of multiband and other sensor techniques for moisture determinations is most promising for agricultural purposes where relatively homogeneous conditions exist at certain times of the year—as for example, in low-lying, plowed fields in the spring.

Thermal IR and passive microwave sensors are also useful for making determinations of moisture conditions in surficial deposits. Moisture greatly affects the thermal response of surface deposits, and anomalously moist areas can appear as distinct tones on infrared and microwave imagery. A certain amount of "depth" information may also be obtained, since subsurface moisture can affect the surface temperature (or emissivity) of deposits and be detected on this basis. Thermal IR and passive microwave sensors are capable of excellent thermal resolution. These sensors show promise as a potential means of deriving quantitative data on moisture content of surficial deposits either used alone or in conjunction with other sensor systems. Imagery can be obtained during the day or night. Optimum sensing time will depend on several factors such as the nature of the terrain, vegetation, season, and present and previous meteorological conditions. Missions should be planned to obtain maximum contrast in ground signals.

Radar energy is sensitive to moisture in surface deposits (affects the strength and polarization of return signals) and to any phenomenon which changes the conductivity or nature of the dielectric properties of materials. Thus, the physical basis exists for the possible use of radar as a means of determining the moisture conditions in surficial

deposits, perhaps on a quantitative basis. Tests by Davis, *et al.* (1966), show promise for radar as a tool for remotely determining, by direct means, the moisture and ground-water conditions of terrain.

Gamma-ray emissions are attenuated by the presence of moisture in surface deposits. Emissions can be monitored and variations in signal count can be theoretically correlated with moisture content. Among other things, however, normal ground-radiation levels must first be determined. The technique would be most promising for homogeneous deposits where normal ground-radiation levels would be fairly uniform. Deal, *et al.* (1971), report the use of an aerial radiation detection and tracking system for determining the water equivalency of snow cover by measuring the attenuation, by the snow cover, of the natural radiation from the ground.

Various active and passive airborne geophysical systems, which monitor the electrical conductivity of terrain, have general application for differentiating between various deposits such as clays, sands, and gravels and also for making gross determinations of moisture conditions of surface deposits. Two such systems, the INPUT and E-Phase™ system, are described by Barringer and McNeil (1969, 1971).

308. MOISTURE PHASE OF SURFICIAL DEPOSIT

(a) Definition: A determination of the frozen or unfrozen condition of the interstitial water in a surficial deposit.

(b) Interpretation Variables: Freezing of the ground surface occurs each year during winter periods over extensive areas of the earth—at high latitudes in temperate regions, and at high elevations at all latitudes. The frozen condition is usually only a temporary phenomenon generally ending with the onset of seasonally warmer weather. In high latitudes and at some high elevations, only partial annual thawing occurs; and some ground remains frozen from year to year (permafrost). In these areas, also, relict frozen ground, or permafrost, which is a product of past periods when climate was colder than at present, occurs. This relict permafrost in some areas such as the Arctic Coastal Plain of Alaska reaches thicknesses of hundreds of feet.

There are several aspects to frozen-ground investigations. In addition to delineating areas of general frozen or unfrozen surface conditions, there may be a need for determining the depth or vertical extent of the frozen profile and for determining ice content. Problems may arise from the existence of a frozen profile beneath a partially thawed surface or from the presence of a snow cover. The ground beneath a snow cover may or may not be frozen since snow can be an effective insulator. Generally, remote determinations of frozen or unfrozen conditions will be less complicated if the ground surface is exposed.

Frozen-ground investigations are aided by considerations of geographic location and climate, freezing indices based on temperature records, etc.

In high-latitude areas where continuous or discontinuous permafrost occurs over extensive areas, its presence is commonly indicated by distinct surface features such as patterned ground, peculiar drainage features, distinct vegetation associations, etc. An experienced interpreter knowledgeable about permafrost—its indicators, mode of formation, areas of likely occurrence, etc.,—can use various types of remote sensor imagery to locate frozen ground and to make many inferences about it.

The pattern indicators of permafrost areas, engineering implications, and interpretation procedures for analyzing aerial photographs and deriving information from them are discussed by Frost (1950, 1960). The identification of vegetation indicators of permafrost from aerial photographs is discussed by Stoeckeler (1949).

The likelihood of occurrence of frozen conditions depends to a large extent on the type of surficial deposit, topographic setting, and availability of moisture. Deposits such as gravels are more likely to remain unfrozen because of high permeability and lack of interstitial water. Fine-grained deposits such as silts are much more likely to be frozen. Because of the thermal effects of water, areas beneath streams, lakes, and ponds will most likely remain unfrozen; although, in high-latitude areas, relict permafrost may occur at depth.

(c) **Remote Sensor Applications:** Aerial photography has use for determining the general frozen or unfrozen condition of surficial deposits. Using photography, the general nature of surficial deposits can be evaluated in relation to the natural and cultural features of the landscape, and key indicators of frozen conditions, such as distinct ground patterns, can be identified. Vertical panchromatic photography has been used extensively in the past for frozen-ground investigations. Infrared-sensitive films may have special value for differentiating between frozen and unfrozen deposits. Color and color IR films would be useful especially where special efforts are made to identify surface deposits and to judge their frost susceptibility in terms of grain size, topographic setting, etc., or where vegetation assemblages are used as key indicators of the presence of permafrost.

Thermal IR and passive microwave sensors would have special application for frozen-ground investigations. Under select conditions, frozen and unfrozen deposits could be differentiated on the basis of thermal and emissivity differences and inferences made on the relative ice content in certain deposits. From thermal IR scanner imagery obtained near Barrow, Alaska, Horvath and Lowe (1968) noted that the frozen central portions of low-center polygons exhibited tones similar to those from nearby frozen lakes indicating high moisture concentration in the central polygon areas. Using thermal

and passive microwave sensors, it may also be possible, under certain conditions, to ascertain whether ground beneath a moderate snow cover is frozen or not.

The air-droppable penetrometer would appear to have use for determining the frozen or unfrozen condition of surficial deposits and for making determinations on depth of the frozen profile.

Various airborne geophysical techniques which measure the electrical conductivity of terrain would have general application for differentiating between frozen and unfrozen deposits and for general mapping of the distribution and thickness of frozen deposits. Two airborne systems which measure the conductivity of terrain, the INPUT and E-Phase™ systems, are described by Barringer and McNeil (1969, 1971).

Airborne seismic and acoustical techniques may also prove to have application for frozen-ground investigations.

309. LOCATION OF FRACTURES

(a) Definition: A determination of the location and general extent of linearly defined zones of weakness in earth materials.

(b) Interpretation Variables: This discussion will be confined to the airborne remote detection of naturally occurring fractures in earth materials such as joints and faults. Some of this discussion would apply, however, to the remote detection of fractures in such man-made features as dams, roads, and airfields. Element 114 treats detection and location of fractures in floating ice, and element 310, fractures (crevasses) in glaciers.

Faults are fractures in the earth's crust along which significant displacement has occurred. Faults may be extensive both horizontally and vertically. Joints are more localized fractures along which little or no displacement has occurred. Present-day fault movements occur in seismically active zones of the earth. The San Andreas Fault of California which extends some 600 miles is an example of an extensive active fault system.

Various types of remote sensing imagery are used to detect fractures primarily through recognition of characteristic surface linear trace and anomalous orientation of surface features, deposits, streams, lakes, etc. Fracture zones also can have high moisture concentrations (from runoff, seepage—even geothermal sources) which may aid in their detection—the fractures exhibiting distinct tones on photography and thermal imagery. Because of the moisture environment, fracture zones may be enhanced by

profuse or distinctly characteristic vegetation which may be used also as a basis for detection.

Fracture zones can also be sites of mineralization and may have high magnetic and radiation levels which may be detectable.

(c) Remote Sensor Applications: Photography has been widely used to detect surface fractures. Large-magnitude fractures, some previously unknown, have been detected from photography (thermal imagery also) obtained from the Apollo program. Low-sun-angle photography has been used to enhance subdued topography and structural features in geographic areas containing highly reflective surface materials and sparse vegetation (Howard and Mercado, 1970). Panchromatic and black and white IR have been the most widely used films for detecting surface fractures. Color and color IR films (prints or positive transparencies) would also be generally useful. Choice of camera, film/filter combination, and photographic format (vertical, oblique, etc.) would depend largely on the geographic area to be investigated, ground conditions, including type and profusion of vegetation, and meteorological conditions. Choice of scale would depend on the size of features being investigated and area to be covered.

Hackman (1965) used aerial photography to investigate faulting and general disruptions after a severe earthquake in Alaska. Earth crustal movements have been monitored and measured using aerial photography obtained over ground reference stations (Woodcock and Lampton, 1964). Numerous fracture analyses have also been conducted using aerial photography (Trainer and Ellison, 1967).

Thermal IR imagery has been used for location of surface and near-surface fractures. Because of moisture concentrations and differences in texture, etc., of materials, surface fractures tend to show up well on thermal IR imagery. Near-surface fractures are also detectable to the extent that they influence surface materials and conditions. Best general results are obtained with pre-dawn imagery. Thermal IR imagery can be a valuable tool in itself or as a useful supplement to photography for conducting general investigations. Mosaics can be made from thermal imagery if careful procedures are followed during airborne acquisition, and these can greatly increase the general usefulness of the imagery (Williams and Ory, 1967).

Radar imagery, SLAR in particular, has special use for detecting surface fractures and evaluating the overall structure of diverse terrain. Radar imagery tends to emphasize morphologic aspects of terrain including drainage channels. The general small-scale and wide-area coverage of radar imagery makes it more suited for reconnaissance and detection of large-magnitude structures than for detailed investigation of smaller features. Much depends on the relative orientation of the radar with respect to the terrain. Best morphologic results are obtained when the radar is flown at low angles

parallel to the geologic, structural, and topographic grain (Wise, 1967). Positive transparencies probably yield the best results (Reeves, 1969). Radar imagery is also a valuable supplement to photography.

Radar has a general day/night and all-weather capability and can penetrate vegetation to a limited extent depending on frequency used. False structural linears, however, can be generated by rows of trees in addition to stone walls and other linear features both natural and cultural.

Non-imaging sensors such as gamma-ray spectrometers and magnetometers have some general use for detecting and locating fractures and fracture zones.

310. LOCATION OF GLACIERS

(a) Definition: A determination of the location and general dimensions of glaciers and associated features.

(b) Interpretation Variables: This section on glaciers was written in conjunction with the ice elements outlined under "Hydrologic Elements" (100 Series). These other elements should be reviewed along with this presentation.

Glaciers are large active natural accumulations of ice and snow generally occurring as tongues flowing out from larger accumulation zones—ice sheets, ice shelves, and ice caps. They occur in the polar regions and in various mountain ranges in all latitudes being the product of positive snow regimes created by various climatic and topographic factors.

The features of glaciers and glaciated topography are unique. In mountains, glaciers give rise to such features as serrate ridges, cirques, U-shaped valleys, kame terraces, and moraines. Deposits include glacial tills and outwash gravels. Mountain glaciers generally exhibit linear bands of incorporated materials, and the stream fed by glaciers are characteristically braided. The glaciers fed by continental ice caps may not exhibit all the features typical of mountain glaciers, but processes of movement and many of the features are similar. Glaciers are discussed and illustrated by Thornbury (1954), Flint (1957), and Lueder (1959).

Glaciers, because they are generally predictable in occurrence and large in magnitude, are easily recognized and located. Remote sensor imagery has been used in the past for locating, mapping, and monitoring changes in glaciers (sequential imaging) and for detailed studies of glacier processes and environments (Konecny, 1964; Case, 1958).

The glacier environment is complex having elements of ice, snow, water, rock, soil, and vegetation. The glacier itself is also very dynamic physically, thermally, and in all other aspects.

(c) Remote Sensor Application: Photographic systems of various kinds have been used for location of glaciers and general glacier studies. Panchromatic and panchromatic IR films have been the most commonly used. Color and color IR films are being used more frequently for both general and special studies. These films allow greater discrimination between the various features and materials in the glacier environment, including greater distinction between snow and ice zones, and greater definition of lineations, open crevasses, meltwater channels, and ponded water.

The complex glacier environment is also an ideal location for experiments with multiband and narrow-band sensing techniques. Multispectral sensing tests have been carried out on South Cascade Glacier, Washington, by Meier, *et al.* (1966).

Low-sun-angle photography can also be of use on glaciers, ice fields, and ice caps for outlining subtle surface features including snow-covered crevasses. Low-light-level photography may also provide good images of glaciers at night under ideal conditions. Both of these photographic techniques may be particularly useful in polar regions where long periods of low-sun-angle and darkness are common.

Because of the generally large magnitude and ease of recognition of glaciers, non stereo, small-scale imagery would probably be adequate for general location and reconnaissance purposes; but, for detailed work, large-scale stereo imagery would be required. The distribution and size of glaciers also allow the use of high-altitude, small-scale imagery obtained for reconnaissance purposes. Simple recognition of outstanding glacier features can be made on photographic imagery by a novice interpreter, however, any detailed analysis would require the services of a trained interpreter.

Glaciers can be readily identified and located on thermal infrared imagery. The imagery also has sufficient resolution and contrast for more detailed investigations. A wealth of thermal signal contrasts is provided in the varied glacier environment. IR imagery may be used alone or in conjunction with conventional photography for additional information content; thermal imagery can be obtained at night under moderate atmospheric moisture conditions.

Poulin and Harwood (1966) discuss the detection of thermal anomalies on glaciers and their significance. IR imagery permits discrimination between snow-covered ice, rock, and soil boundaries and allows evaluations to be made on the various stages of freezing of glacier lakes and the relative depth of snow on the lakes. Discrimination can also be made between active and inactive stream channels. The differential thermal

signals can be used as clues to dynamic processes occurring on and within the thermally sensitive glacier ice mass.

IR radiometers and spectrometers can also be used to give additional information on the thermal regime of glaciers and can be used in conjunction with IR scanners. Use of IR imagery and data for detailed analysis of glaciers and glacier environments requires a skilled interpreter; for simple location purposes a less skilled worker would suffice.

Thermal IR imagery has been used on the Greenland Ice Cap to locate snow-covered crevasses which were undetectable or only slightly evident from the air (Rinker, 1966). Although low-sun-angle photography will sometimes help to outline these features, they are much more apparent on IR imagery. The crevasses, being open features, hold air which maintains a relatively constant temperature. This air pumps in and out of the crevasses and gives rise to a thermal signal on the IR imagery which generally contrasts with the signals from the surrounding surfaces. In general, the crevasses will appear colder during the day (when surrounding surfaces are warmed by the sun) and warmer at night.

Detection of crevasses is extremely important for planning cross-country movements of men and equipment. In addition, vehicles and the snow-packed trails of vehicles can generally also be detected on IR imagery.

Microwave imagery can also be used for glacier location and study in much the same manner as IR imagery although spatial resolution is much poorer. Microwave, however, has the advantage of being able to obtain imagery under conditions of atmospheric moisture which would inhibit use of thermal IR.

High-frequency SLAR can rapidly provide quality imagery of glacier areas. The small reconnaissance scale of the imagery has sufficient resolution for general studies of glaciers. Gross surface features can be generally identified; these include lineations and crevasses in the glacier ice, major changes in roughness and flow patterns, major ice/rock boundaries, lineations in bedrock, and major drainage patterns (depending on amount of relief). The strength of the signal returns depends on the type of material, surface roughness or relief, and orientation with respect to radar sensor. Leighty (1966) lists the various surface materials of a glacier area (margin of the Greenland Ice Cap) in order of generally diminishing signal return: snow, glacial ice, soils and rocks, lake ice and sea ice, and open water. The snow-packed trails and roads on the ice cap also showed up well on the imagery presented by Leighty (1966).

Radar returns from glacial ice may be influenced by ice temperature and surface moisture (reflective returns being stronger from wet ice) as indicated in studies

by Sheps (1957) of PPI radar imagery (Xband) of Greenland versus Antarctic glacial conditions.

Radar can provide imagery in daylight or darkness and under adverse weather conditions. It has proven to be a valuable reconnaissance sensor in the Arctic. Use of radar imagery for glacier studies requires an interpreter experienced in radar imagery as well as in general glacier investigations.

Low-frequency depth sounding of glaciers and ice caps is discussed under the category Ice Thickness (113).

The laser profilometer has uses for study of the surface features and roughness of glaciers but not as a prime locating sensor. The penetrometer, also, although potentially useful for specific sampling programs, is not a prime locating sensor.

The environmental factors affecting the acquisition and interpretation of remote sensor imagery for study of glaciers are largely the same as those discussed under Ice Type (115). In addition, however, the high elevation of many mountainous areas where glaciers occur may create operational problems in acquiring imagery, and the great variations in relief may affect the mensuration quality of the imagery—especially photography. Certain environmental phenomena, such as the occurrence and intensity of diurnal winds and temperature inversions, may also be more prevalent in glacier areas than in less diverse terrain.

311. LOCATION OF VOLCANOES

(a) **Definition:** A determination of the location and general dimensions of volcanoes and associated features and deposits.

(b) **Interpretation Variables:** A volcano is "a vent in the earth's crust from which molten lava, pyroclastic materials, volcanic gases, etc., issue" (American Geologic Institute, 1960). Topographically, the term "volcano" refers also to the cone or mountain which is sometimes built up from extruded or ejected materials.

There are many types of volcanoes and many classifications based on types of eruptions, magnitude, and nature of build-up of volcanic mass, etc. Volcano classifications are reviewed by Thornbury (1954). Volcanoes may exhibit cones or cone-like masses of basalt and/or cinders, be of large or small proportions, and exhibit craters or collapsed structures. Eruptions may take place along extensive fissures and form lava plateaus without any formation of cones or similar features. Volcanoes may occur individually or in groups, be youthful, and exhibit a bold outline or may be old and extensively eroded. Little or no surface trace may be present, or only a column or ridge of

rock may protrude above the ground surface marking the site of a neck or pipe of a former volcano. Identification is most simple in the case of a well-developed, active volcano.

Active volcanoes occur in distinct geographic areas of the earth's surface, characteristically in active zones or belts such as the circum-pacific belt. Inactive volcanoes also occur in these zones and also in old mountain chains throughout the world. The location of many of these ancient volcanic centers is known only approximately through such indirect evidence as thickness trends of associated extensive volcanic deposits.

In regard to remote sensing, volcanoes, like other natural terrain features, should first be broken down into prime characteristics and then evaluated in terms of the remote sensor or sensor combinations best suited for acquiring information on these characteristics under given environmental conditions. The prime characteristics of volcanoes, some of which have already been mentioned, include the volcanic mass or cone, crater, fissures, active gases, lava, and pyroclastic deposits. If the volcano is active, its surface and subsurface heat sources can also be used as a means of detection. All of the above characteristics help to identify a structure as a volcano and serve as a means of interpreting its processes, relative age, geologic history, etc.

A crater is a prime characteristic of a volcano. When the crater is of exceptional magnitude, the term "caldera" is generally used. These craters may be explosive in origin or due to a combination of explosion and collapse.

Other crater-like features which may not be volcanic in origin exist on the earth's surface. Some craters, such as Meteor Crater, Arizona, are thought to be meteor-impact sites. The terms "cryptovolcanic" and "astrobleme" have been used to refer to crater-like structures of doubtful origin. Bomb craters, excavation pits, etc., may also superficially resemble volcanic craters. Much research on crater morphology and mechanisms has been stimulated by the lunar exploration programs of the U. S. and U.S.S.R.

(c) **Remote Sensor Applications:** Photography, especially vertical panchromatic, has been the most commonly used type of remote sensor imagery for general geomorphological investigations of volcanoes. Volcanoes have been identified and located, and their deposits and geologic history of growth and erosion have been investigated with the aid of photography. The general application of photography and other types of remote sensor imagery to the study of volcanoes is reviewed by Fezer (1971).

Useful scales for photographic (other imagery also) detection and study of volcanoes will depend on their size and boldness of expression and resolution and overall quality of the photography. Useful information may even be obtained from orbital

imagery. Active or youthful volcanoes will generally be easier to identify than old and subdued ones. Novice interpreters should be able to detect and identify well-defined volcanoes even from monoscopic aerial photography, although stereo viewing is always desirable.

Color photography and color IR would probably be more useful than panchromatic for detailed investigations of volcanoes and volcanic terrain. Discrimination of materials, vegetation, and drainage features would theoretically be easier to make using color and color IR films. Multiband photography would also be useful for investigation of volcanic materials and volcanic terrain as would quality imagery from electro-optical imaging systems. Good interpretive results, for instance, have been obtained using television-type imagery of the moon's cratered surface.

Thermal IR scanners and radiometers have been widely used to detect and study active volcanoes. Detection of new volcanoes has also been accomplished by high-resolution thermal radiometers operating from orbiting platforms. Thermal imagery can provide information on surface and subsurface thermal patterns of volcanoes.

Near-surface magma concentrations and active conduits can be detected and the migration of molten lava traced with the use of thermal sensors. IR spectrophotometers have been used to provide information on the concentrations of various volcanic gases (Naughton, *et al.*, 1969). Thermal imagery is also useful for differentiating between various lava flows and other volcanic deposits such as ash layers.

Radar imagery can be used for detection of volcanoes especially on a reconnaissance basis. Large, well-defined volcanoes should be easy to identify by shape alone, but more subtle features may escape detection. Volcanic materials should also generate characteristic identifiable patterns on radar imagery. Radar scatterometers have been used experimentally over volcanic terrain to produce data on surface roughness, particle size, and topography (Quade, *et al.*, 1970).

Gamma-ray sensors, magnetometers, and gravimeters have highly specialized uses for the evaluation of volcanic areas.

312. LOCATION OF LANDSLIDE PHENOMENA

(a) Definition: A determination of the location and general dimensions of landslides and related phenomena.

(b) Interpretation Variables: A landslide can be defined as a sudden movement of earth and rocks down a steep slope. (American Geological Institute, *Glossary of*

Geology and Related Sciences, 1966). The term "landslide" can also refer to the track or scar left by the slide and the materials involved.

Many varieties of slope movements can occur. They are classified according to the type of material involved, kind of movement (rotational, translational), rate and magnitude of movement, etc. All are debris movements or mass wasting of various kinds and have a variety of names, for instance, landslip, avalanche, rockslide, mudslide, earthflow, and slump. Some slope movements are gradual and of limited distance; others are catastrophic and can move debris great distances. Classifications and detailed discussions of landslides and related phenomena are given by Sharpe (1960) and Eckel (1958). Eckel uses the term "debris avalanche" in much the same sense as the above definition of landslide. A sudden mass movement consisting largely of snow and ice would presumably be referred to as a snow avalanche.

Many factors affect the strength of slope materials. Some of these are: the type of material–its composition, structure, density, porosity, permeability, cohesion, and internal friction of particles; steepness and length of slope; soil moisture; and type of vegetation. Moisture content is an especially important factor, because it lessens the strength of the soil or rock mass by increasing pore pressure and weight. Slope failures characteristically occur after periods of heavy rainfall. Earth tremors are exceptional phenomena that may cause otherwise stable slopes to fail at any time. Man can create conditions leading to landsliding by logging and building roads and dams.

In addition to identifying and locating landslides and like features, there are also the problems of identifying landslide-prone areas and predicting landslides. In thise report, the discussion of remote sensing of landslides will be largely limited to problems of identification and location. The other two categories are more artful in approach and require an extensive knowledge of landslide phenomena–especially the prediction aspect.

The most apparent feature of a landslide that would aid in its identification and location would be the scar marking the origin and path of the slide. All downslope debris movements, however, do not exhibit obvious scars or distinct sliding planes; and, in these instances, other identifying features must be used.

The slide scar can be recognized by its downslope, elongated shape, and contrast with surrounding terrain. A fresh slide of large proportions, possibly involving the removal of trees and other vegetation, would theoretically be easy to recognize. Old scars would be less evident especially if reforested, although the scar pattern could be reflected in the reforestation pattern (the outline of the forest pattern, its composition, and age distribution). Such vegetation patterns may also serve as indicators of the approximate age of the original disruptive event.

A landslide scar usually persists for a long time and may be marked by a stream or gully. Often, a landslide or associated event sets the stage for subsequent disruptions. Movements of soil, rock, and other debris can occur along the original slide path. Cracks may appear above incipient slides. Such considerations enter into landslide prediction and identification of landslide-prone areas.

A landslide may also be identified from the downslope accumulations of rubble. This is especially true in situations where debris is strung out on the glacier, playa, or other contrasting surface. In addition to the recognition of the actual debris pile, cone, or trail, the disruption of drainage and other patterns would serve as indicators of landslide activity.

Talus cones may mistakenly be identified as landslide rubble by an inexperienced interpreter. The processes of accumulation are somewhat similar although the time frame is drastically different. The gradually accumulated talus piles or cones would, however, serve as indicators of potential landslide areas.

(c) **Remote Sensor Applications:** Aerial photography is probably the most useful remote sensor system for identification and location of landslides and related phenomena. It is the most common sensor system used in the past and probably will be in the future.

Swanston (1969), for instance, reports on the results of an extensive air-photo survey of landslides in the Tongass National Forest of southeast Alaska. More than 3,800 large debris avalanches and flows were detected, most having occurred in the last 150 years; older movements were generally not apparent on the air-photos (panchromatic).

Stereophoto coverage is generally desirable for landslide detection but not always essential. Large, fresh slides may be detected by a less experienced interpreter; but older, more subtle, or obscured features would require a more experienced interpreter.

Vertical photography is generally adequate, but occasionally other photographic formats such as oblique may be more desirable. Depending on type of terrain, vegetation, atmospheric conditions, etc., one special film/filter combination and scale may yield more information than another.

In a comprehensive study in the southern Appalachian Mountains by Poole (1969), a variety of slope-failure forms from sheet-wash erosion to large, ancient landslides were investigated, and evaluations were made on the capability of various types of aerial photography to supply information on them. Criteria for identifying these features

were also given. Color and color IR transparencies proved excellent for study of all slope-failure forms including major and minor characteristics, associated vegetation, and soil moisture conditions. Small-scale photography on the order of 1:20,000 was judged most appropriate for general studies (large and small features), and scales on the order of 1:10,000 or larger were considered more appropriate for smaller features.

Dishaw (1967) reports on the use of very small-scale photography (on the order of an inch-to-the-mile) for detecting massive landslides whose great dimensions make them difficult to detect on the ground or from large-scale imagery. Dishaw also outlines techniques for recognizing these massive slides from air photos.

Measurements of landslides are possible on imagery of appropriate scale and quality. Snow avalanches have even been sequentially photographed from ground stations while in progress, and critical measurements have been made from the photography (van Wijk, 1967).

Thermal infrared imaging sensors would have application for location of landslides. The low-light and night capabilities of this sensor may be especially useful in certain instances. Thermal contrast between the slide area and its surroundings, however, would have to be sufficient for detection and identification. A landslide would expose new surfaces with associated water conditions and would disrupt normal thermal patterns such as vegetation. Such thermal contrasts, therefore, may be common. Thermal infrared imagery might also be valuable for studying the moisture regime of a slide area—a critical factor. The limited resolution of the imagery would be a restricting factor, and its use would require an experienced interpreter.

Non-imaging radiometers and lasers would have little application for landslide location. The point data or line trace presented by these sensors may be useful for providing quantitative data on the dimensions and thermal regime of a slide area but not as a primary detector.

Other non-imaging systems, such as magnetometers, gravimeters, penetrometers, etc., would generally have little application for detection of landslides. The penetrometer, however, may have value in investigating subsurface conditions in slide areas.

Radar, especially SLAR, may have some usefulness for locating landslides. In general, however, the limited resolution and small scale of the radar imagery would make detection of landslides difficult except for very large features or special situations such as large slides on vegetated slopes. Radar imagery may be more useful for searching for prime landslide areas on a reconnaissance basis. The presentation of topography and structure in stark outline over large areas would be useful for such purposes.

Supplemental photography at large scales could be subsequently used for closer inspection of suspected landslide areas.

Environmental factors affecting the identification and location of landslides from aerial imagery include obscuration by vegetation, snow, and ice. Other factors include the magnitude of the slide feature, its boldness of expression, and its contrast with surroundings. Atmospheric factors are always a consideration.

313. LANDFORM ELEVATION

(a) Definition: A determination of the vertical distance of an object or feature above some datum.

(b) Interpretation Variables: The terms "elevation," "height," and "altitude" are similar in that each refers to the vertical distance above some stable plane of reference, although, there is a tendency in the United States to limit the term "elevation" to the vertical distance above mean sea level. Other elements in this report treat special height or elevation topics such as tree height and bank height. Element 314 (Slope Angle) also contains pertinent information.

There are several remote sensors which can yield data on elevation or vertical distances of features above given levels. Some of these sensors produce images and others, direct point or line data. The imagery from these various sensors differs in quality and resolution. Vertical aerial photography is probably the most commonly used imagery for producing elevation data, it is versatile and is inherently capable of excellent spatial resolution.

(c) Remote Sensor Applications: All photographic systems producing dimensionally correct or correctable stereo imagery of appropriate quality, scale and resolution can theoretically yield useful elevation data. This applies also to the various photographic imagery formats such as vertical, oblique, and strip. Elevation data are also possible on a limited basis from select single photographs; but, in general, stereo coverage is necessary. Vertical aerial photography, generally, has the simplest geometry; other formats such as panoramic are more complex.

A variety of methods may be used to extract elevation data from photographs. Elevations of features can be simply estimated or measurements made with desk-type instruments or sophisticated plotting machines. The accuracy and precision of such methods are affected by a number of factors chief among which are scale, overall control, and image quality. The usefulness of any scale depends on the size of the feature to be measured and the degree of accuracy required (in addition to contrast and image quality).

The determination of elevation and slope data from imagery generated by electro-optical systems, thermal scanning systems, and passive microwave systems is discussed under element 314 (Slope Angle). Techniques for obtaining elevation and slope data from radar imagery are also discussed under element 314.

A combination radar altimeter and aneroid barometer—the Airborne Profile Recorder (APR)—is used to obtain elevation and slope data on terrain. The radar altimeter measures the vertical distance between the aircraft and the terrain, and a differential barometric instrument records the deviation of the aircraft from a set barometric datum. A profile of the terrain surface is thus obtained. The radar APR's include low-altitude FM and pulsed radars and specialized narrow-beam equipment. Height accuracy of the APR is affected by the fact that the signal returns are integrated over the entire area of illumination; and, in locally irregular terrain, profiles may be smoothed. For a 1-degree, narrow-beam APR, the ground diameter of the area of illumination from a 5,000-foot altitude would be about 88 feet. Height accuracy can be on the order of .5 percent of the flight altitude. The narrow-beam APR can be used at low or high altitudes and under adverse weather conditions during the day or night.

The laser terrain profiler (LTP) operates in a manner similar to the APR except that a very narrow beam of light is used for ranging. Depending on the type of equipment and narrowness of the laser beam, the illuminated spot on the ground can be only a few inches in diameter from an altitude of 5,000 feet. Under good conditions, the height resolution can be on the order of .2 percent of the altitude. The LTP is especially useful for obtaining height data on small features, although background "noise" can be a problem. Profiling may be conducted with a continuous laser or pulsed laser, the continuous laser generally having a greater accuracy. The continuous laser profiler can be used from high altitudes and the pulsed laser, theoretically, from very high altitudes. In addition to providing a profile of the terrain surface, the LTP (APR also) can be used as an accurate altimeter to provide altitude data for calculating exact scale for photography.

The LTP generates a linear surface profile of the terrain and is generally supplemented with some type of track photography for location purposes. It is theoretically possible to develop a scanning laser (some obvious shortcomings, however) in which a much wider swath would be illuminated. Like all sensors, the laser is affected by certain environmental factors such as sunlight, atmospheric temperature, and moisture. The total interaction of the essentially monochromatic light beam of the LTP with various surface materials is also incompletely known, and anomalous returns can affect the profile data. Despite some limitations, the LTP is a useful profiling sensor.

314. LANDFORM SLOPE ANGLE

(a) **Definition:** A determination of the angle at which a surface deviates from the horizontal.

(b) **Interpretation Variables:** The slope of terrain features can be expressed in terms of degrees or percent or as a ratio. Slope can be determined by any method which yields data on horizontal or map distance versus elevation. Slope data can be derived from a variety of remote sensor imagery producing a dimensionally accurate image of suitable scale. Sensors can also be matched to guarantee accurate height and horizontal distance data. Since elevation data are necessary for calculating slope, element 313 (Elevation) should be read in conjunction with this discussion. Accurate horizontal data are also necessary for making slope calculations and for determining exact locations. The geometry of various types of remote sensor imagery is discussed under element 303 (Area of Surficial Deposit).

(c) **Remote Sensor Applications:** Aerial photography is most commonly used for obtaining slope data. Photography inherently has the best overall resolution and metric quality of the various types of remote sensor imagery. Vertical photography is the easiest to work with and has the simplest geometry. Measurements and rectification procedures are more complicated with other photographic formats such as oblique and panoramic. For certain purposes, however, formats other than vertical will be desirable. Some slope information (height/horizontal distance) is possible from single vertical photographs, but stereo coverage is generally necessary. Orthophotos can be helpful in determining slopes and exact locations.

The selection of photographic format, film, and scale for determining specific slope data will depend on the type and magnitude of the feature or features being investigated and the prevailing environmental factors including atmospheric conditions. Color and color IR films would offer the greatest ease of discrimination of features and delineation of boundaries; however, for the most simple slope determinations, other films such as panchromatic would suffice.

The level of skill required to extract slope data from photography (other types of imagery also) depends on a number of factors including the type of instrumentation which can range from simple to complex. Generally, a certain level of skill is required for even simple slope determinations since a representative slope must be chosen, various ground conditions (vegetation, snow cover, etc.) must be dealt with, and accurate measurements must be made in the true, down-slope direction (analogous to true dip and apparent dip in geologic parlance). Estimates of slope also require a certain level of experience. Novice interpreters tend to generally overestimate the slope of natural

terrain features due to vertical exaggeration when using photography. Slopes of most natural landforms are generally under 30 degrees.

Slope and elevation data can be obtained, with varying degrees of accuracy, from a variety of remote sensor imagery other than photography. Much work is currently being done on the theory and actual development of a stereo capability for the more exotic remote sensing systems. As pointed out by Derenyi and Konecny (1966), "stereo imagery is the only means to locate and identify objects properly."

Stereo techniques initially require a highly accurate mathematical description of the parallax factors and relief displacement factors involved. This has not yet been well done for all sensors. All techniques for determining slope and elevation data must also employ both vertical and horizontal references.

Various electro-optical imaging systems, including television-type systems, are theoretically capable of producing images of good resolution and geometry. Within limitations, some height and slope data are probably possible from select, single, video-type images. Generally, however, reliable height and slope data must be extracted from stereo imagery produced by these systems.

Thermal-scanner imagery lacks the definition of photography and television-type, electro-optical systems. Such scanner imagery, however, can have good geometry if stringent internal and external controls are exercised during acquisition. Horizontal geometry can be especially good in the azimuth or track direction but is more complicated in the scan direction. Stereo imagery can be obtained by overlapping flight lines or by use of a stereo scanner (Derenyi and Konecny, 1966). Rectification of the imagery requires sophisticated instrumentation. The resolution and geometry of IR scanner imagery (other electro-optical scanner systems also) probably will continue to improve with future systems utilizing highly sensitive detector arrays and advanced stabilization systems.

The spatial resolution of imagery generated by passive microwave systems is generally too poor at present for practical consideration as a means of deriving useful slope and height data.

Since radar is a unique active ranging system, elevation and slope data can be obtained from radar imagery. SLAR imagery, especially, has been widely used as a mapping tool. Stereo SLAR mapping techniques are also being currently investigated and show promise. The best results are obtained when the terrain is viewed from opposite sides at the same elevation and look angle (45 degrees being optimum).

Because of the generally small scale of radar imagery and limited resolution and tonal contrasts, slope data from radar imagery are generally restricted to large features and to determinations of regional slope. The regional data can be quite useful, however, for slope determinations on large watersheds and for general geomorphic studies. The derived data in many instances is comparable to that obtained from topographic maps prepared from aerial photography.

The various techniques for obtaining elevation and slope data from radar imagery are discussed at length by Lewis (1971). These techniques are:

relief displacement
radar shadowing
radar foreshortening
radar power return.

A variation of the radar-shadowing technique has been used to make general determinations of regional backslope in mountainous terrain by noting the depression angle at which radar shadowing first occurs Lewis and Waite (1971) discuss at length the experimental application of this technique.

Some other attempts at producing stereo radar imagery include the simultaneous procurement of radar and IR scanner imagery (Moore, 1969). The parallax displacement is in opposite directions on the two kinds of imagery providing the necessary criteria for stereo viewing. Pseudo-stereo effects have also been produced by superimposing positive and negative radar transparencies.

Height and slope data can also be obtained with airborne laser and radar altimeter profilers. These sensors are discussed in detail under element 313 (Elevation).

315. LANDFORM PROFILE

(a) **Definition:** A determination of the relief outline of a landform along a given azimuth.

(b) **Interpretation Variables:** A discussion of landform profile determinations from remote sensor imagery must consider many of the same factors discussed under the elements: Area (303), Elevation (313), and Slope (314). The reader is referred to these discussions for additional information since the subject of profile determinations will be only briefly treated here.

(c) **Remote Sensor Applications:** Landform profiles can be determined from stereo aerial photography of sufficient resolution and mensurable quality. The techniques,

skill, and equipment required vary with the type of photography (vertical, oblique, panoramic, etc.), its overall quality, and the accuracy required.

Landform profiles can be obtained also from imagery generated by electro-optical imaging systems. Television-type sensors are capable of providing quality stereo imagery from which profile data can be extracted. The limited spatial resolution of thermal IR scanner imagery restricts its usefulness for determining landform profiles; however, generalized profiles of larger features can be obtained.

The poor spatial resolution of passive microwave imagery severely restricts its use for profile determinations.

Landform profiles can be obtained from a variety of radar imagery including SLAR but are generally limited to features of large magnitude.

The radar terrain profiler—a specialized combination of a radar altimeter and barometric reference device—can provide relatively detailed profiles of the terrain surface over which it passes. The laser terrain profiler can perform a similar function and is capable also of recording detail of the surface roughness of landforms.

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Table IV. Landforms and Surficial Materials Elements

MILITARY GEOGRAPHIC INFORMATION REMOTE SENSOR MATRIX

	UV	PANCHROMATIC				COLOR				COLOR IR				PAN IR			
*	A	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4
301 TYPE OF SURFICIAL DEPOSIT	1	1	1	1	1	A 1	1	1	1	B 1	1	1	1	1	1	1	1
302 COMPOSITION OF SURFICIAL DEPOSIT	1	1	1	1	1	A 1	1	1	1	B 1	1	1	1	1	1	1	1
303 AREA OF SURFICIAL DEPOSIT	2	C 2	2	2	2	A 2	2	2	2	B 2	2	2	2	2	2	2	2
304 THICKNESS OF SURFICIAL DEPOSIT	1	C 1	1	1	1	A 1	1	1	1	B 1	1	1	1	1	1	1	1
305 COLOR (RELATIVE) OF SURFICIAL DEPOSIT	X	X	X	X	X	A 2	2	2	2	B 1	1	1	1	X	X	X	X
306 TEXTURE OF SURFICIAL DEPOSIT	1	C 1	1	1	1	A 1	1	1	1	B 1	1	1	1	1	1	1	1
307 MOISTURE CONTENT OF SURFICIAL DEPOSIT	1	1	1	1	1	1	1	1	1	A 1	1	1	1	1	1	1	1
308 MOISTURE PHASE OF SURFICIAL DEPOSIT	1	1	1	1	1	1	1	1	1	A 1	1	1	1	1	1	1	1
309 LOCATION OF FRACTURES	1	1	1	1	1	1	1	1	1	A 1	1	1	1	1	1	1	1
310 LOCATION OF GLACIERS	2	B 2	2	2	2	A 2	2	2	2	2	2	2	2	2	2	2	2
311 LOCATION OF VOLCANOES	2	C 2	2	2	2	A 2	2	2	2	2	2	2	2	2	2	2	2
312 LOCATION OF LAND-SLIDE PHENOMENA	1	C 1	1	1	1	B 1	1	1	1	A 1	1	1	1	1	1	1	1
313 LANDFORM ELEVATION	1	B 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1
314 LANDFORM SLOPE ANGLE	1	B 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1
315 LANDFORM PROFILE	1	B 1	1	1	1	A 1	1	1	1	1	1	1	1	1	1	1	1

	MULTI-BAND	NARROW BAND	T.V.	MULTI-SCANNER	IR SCANNER	MICROWAVE	RA RADARS	SA RADARS	GAMMA-RAY	RADIOMETRIC SPECTROMETRIC	LASERS	MAGNETOMETRIC	GRAVIMETRIC	SPECIALIZED ELECTRONIC	PENETROMETER
*	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
301 TYPE OF SURFICIAL DEPOSIT	C 1	C 1	1	1	1	1	1	1	0	0	0	0	X	0	0
302 COMPOSITION OF SURFICIAL DEPOSIT	C 1	C 1	1	1	1	1	1	1	0	0	0	0	X	0	0
303 AREA OF SURFICIAL DEPOSIT	2	2	2	2	1	1	1	1	X	X	X	X	X	X	X
304 THICKNESS OF SURFICIAL DEPOSIT	1	1	1	1	1	1	1	1	X	0	0	0	X	1	1
305 COLOR (RELATIVE) OF SURFICIAL DEPOSIT	C 1	1	1	1	X	X	X	X	X	0	X	X	X	X	X
306 TEXTURE OF SURFICIAL DEPOSIT	1	1	1	1	1	1	1	1	0	0	0	X	X	0	0
307 MOISTURE CONTENT OF SURFICIAL DEPOSIT	B 1	B 1	1	1	C 1	C 1	0	0	0	0	0	X	X	0	0
308 MOISTURE PHASE OF SURFICIAL DEPOSIT	B 1	B 1	1	1	C 1	C 1	0	0	0	0	0	0	X	0	1
309 LOCATION OF FRACTURES	1	1	1	1	C 1	1	B 1	B 1	0	0	0	0	0	0	X
310 LOCATION OF GLACIERS	2	2	2	2	C 2	2	1	1	X	0	X	X	X	0	X
311 LOCATION OF VOLCANOES	2	2	2	2	B 1	1	1	1	0	0	X	0	0	0	X
312 LOCATION OF LAND-SLIDE PHENOMENA	1	1	1	1	1	1	1	1	X	0	X	X	X	X	X
313 LANDFORM ELEVATION	1	1	1	1	1	1	1	1	X	X	C 1	X	X	X	X
314 LANDFORM SLOPE ANGLE	1	1	1	1	1	1	1	1	X	X	C 1	X	X	X	X
315 LANDFORM PROFILE	1	1	1	1	1	1	1	[illegible]	X	X	C 1	X	X	X	X

*For B through E: 1 = vertical; 2 = oblique; 3 = strip; 4 = panoramic.
See Table I for Sensors. Letters over each column correspond to listing in Table I.

12. **Explanatory Notes for Cultural Elements (400 Series).**

a. **Evaluation of the 400 Series.**

401. FOOT TRAIL ALIGNMENT

(a) **Definition:** A determination of the position of foot trails. "Foot trail" refers to the trace made by pedestrian, pack animal, or two-wheeled vehicle (bicycle, etc.) traffic over the terrain in a cross-country manner, usually with sufficient frequency to cause permanent disturbance of such natural features as vegetation or ground conditions.

(b) **Interpretation Variables:** A major environmental condition affecting location of foot trails from aerial imagery is vegetation. Under dense, closed-canopy forests (tropical rain forest), it may be impossible to locate trails by aerial means; although it may be possible to detect segments of trails as they emerge from under the forest canopy in natural or man-made clearings. Location of foot trails under seasonal forest canopies (i.e., monsoon forests, scrub forests, some mid-latitude forests) is easiest, but not always possible, during the season with least vegetative activity (dry or cold season). Usually, trails are readily located in grassland, desert, and polar or alpine environments.

Larger image scales are required in forested regions than in non-forested regions. Although no specific requirements for determining foot-trail alignment have been found, it is possible to give the following estimates based on military interpretation handbook data (TM 30-245). In forested regions, 1:10,000 or larger scale imagery is needed. In non-forested regions, medium- and small-scale imagery would be adequate (up to about 1:60,000).

(c) **Remote Sensors Applications:** Aerial photographic systems (vertical mode) yield the most useful images (Sensor B-G) for trail-alignment determinations. Thermal scanner imagery (8-14) will also provide suitable resolution for this MGI element. Radar and other sensors that provide an oblique view are usually not suitable since they do not provide the necessary aerial patterns needed to determine trail alignment.

In general, aerial photography B1, C1, D1, and E1 obtained at a scale of 1:40,000 or greater will provide enough data to detect foot-trail alignment.

402. ROAD WIDTH

(a) **Definition:** Road width is measured normal to the road centerline and includes the traveled way and any shoulders.

(b) **Interpretation Variables:** There are relatively few environmental conditions impeding road-width determination. In dense forest regions, the forest canopy may extend over portions of the local roads; and, in regions with snow, roads may be temporarily obscured during winter months.

Image scales needed to determine road width will vary according to the accuracy desired. For detailed, accurate measurement, scales greater than 1.5,000 would be needed. Image scales to 1:80,000 may be used (TM 30-245), but as scale decreases, accuracy decreases.

(c) **Remote Sensor Applications:** (Since road-width determination involves the translation of remote sensor data to quantitative measurements, it is important that the data be free of distortions.) A wide range of sensors may be employed, but the photographic systems would provide the best results. Vertical photography offers the easiest means, although it is possible to obtain road-width measurements from oblique and other modes of photography. Group II remote sensors (H-J) and Group III remote sensors (K-M) may be used for relatively coarse measurements. Laser profilers would seem to offer some potential.

In photographic imagery, road-width determination is a relatively simple photogrammetric procedure for vertical photography but is more complex in other modes (oblique and panoramic).

403. ROAD SURFACE COMPOSITION

(a) **Definition:** The natural and/or man made materials used for the traveled way and shoulders of a road are classified as follows: dirt (includes gravel and macadam), brick, wood, concrete, and bituminous.

(b) **Interpretation Variables:** As in the case of MGI element 402 (Road Width), there are few environmental situations which would interfere with road-surface composition interpretation. Snow cover and forest canopies would offer some hindrance, but the former is temporary or seasonal and the latter would not likely cover very lengthy stretches of road.

Road surface composition may generally be interpreted from large-scale imagery (1:5,000) to small-scale imagery (about 1:60,000) given excellent image quality of the appropriate type.

(c) **Remote Sensor Applications:** A number of studies have been completed on evaluating road-surface condition; and, while these studies go beyond determining

simple road-surface composition (i.e., pavement condition), they offer some evaluation of different imagery types but all are of the photographic family of remote sensors.

404. RAILROAD ALIGNMENT

(a) **Definition:** A determination of the location of railroad, roadbed, and tracks.

(b) **Interpretation Variables:** Environmental factors interfering with the interpretation of a railroad right-of-way are extremely limited. Railroad alignments can readily be determined due to characteristic patterns of curves and conjunction points as well as grading accommodations (i.e., absence of steep grades). Temporary obscuration of minor, narrow-gauge lines in tropical forest regions may be encountered where forest canopies hang over the railroad roadbed.

According to TM 30-245, scale may vary from 1:30,000 to larger scales for identification, whereas detailed analysis may require 1:8,000 scale and larger. The latter figure is, however, not applicable to the task of alignment determination but relates to such determinations as gauge. The value given by TM 30-245 is extremely conservative since experience has indicated that alignment of railways may be determined from scales as small as 1:80,000.

(c) **Remote Sensor Applications:** There appear to be few limiting factors in the application of remote sensors other than that the output presents an image of a tract of the earth's surface. While all photographic systems can be used with ease, it is also possible to use various scanner type systems including radar.

405. NUMBER OF RAILROAD TRACKS

(a) **Definition:** A determination of the number of pairs of rails on a railroad roadbed.

(b) **Interpretation Variables:** As in the case of element 404 (Railroad Alignment), there are no serious environmental factors which would interfere with a determination of the number of railroad tracks. The principal limitation is scale. According to TM 30-245 (1967), minimum scale for detailed interpretation is about 1:8,000.

(c) **Remote Sensor Application:** This MGI factor is virtually impossible to ascertain from radar-type imageries; and, hence, photographic radar systems are the most valuable if given a scale as cited above.

406. BRIDGE LENGTH

(a) Definition: A measurement of the total length of bridge.

(b) Interpretation Variables: Environmental situations which would hinder a determination of bridge length are extremely limited. Overhanging vegetation in dense forest regions may offer some hindrance by obscuring bridge approach areas. As with most of the target-type MGI elements (i.e., bridge clear width, area dimensions of buildings, etc.), edge definition or discrimination is the most important factor in detection and measurement of the object. The sensor that provides the interpreter with the greatest degree of contrast between the target or object and its background would, therefore, be the best sensor. Scale limitations for a reliable determination are about 1:30,000 to 1:10,000 according to TM 30-245.

(c) Remote Sensor Applications: Vertical aerial photography is likely to provide the best results, although oblique photography may be more useful since other MGI's concerning bridges may also be obtained from oblique photography. Bridge-length measurement may be obtained through simple photogrammetric procedures. (See *Manual of Photogrammetry*, 1966.)

407. BRIDGE CLEAR WIDTH

(a) Definition: A measurement of the distance between bridge supporting piers or abutments.

(b) Interpretation Variables: There are virtually no serious obstacles to measurement of bridge clear width. Generally, a reasonably large scale would be required and 1:10,000 is given by the Department of Defense (1967). Photogrammetric procedures for analysis of oblique photography would have to be used as outlined in the *American Society of Photogrammetry Manual.*

(c) Remote Sensor Applications: The principal tool for the above measurement is likely to be photography; however, oblique modes are necessary so that bridge piers and abutments are visible.

408. BRIDGE CLEARANCE

(a) Definition: A measurement of the distance between the floor of a road or railroad bridge span and the surface of the feature being bridged.

(b) Interpretation Variables: Same as for element 407.

(c) **Remote Sensor Applications:** Same as for element 407.

409. AREA OF BUILDINGS

(a) **Definition:** A measurement of the horizontal surface area covered by a building.

(b) **Interpretation Variables:** As this is most often an element associated with urban areas, there are generally no important hindrances provided by any aspect of the environment. Basically, the measurement involves simple geometrical problems concerned with areas of various shapes. Scale is an important factor; and, according to TM 30-245 (1967), scales of at least 1:12,500 would be needed for reliable measurement.

(c) **Remote Sensor Applications:** Generally, vertical aerial photography (of most any type) in which scale limitations are not serious is most useful. It is possible also to obtain cruder measurements of area from various scanner outputs.

410. DENSITY OF BUILDINGS

(a) **Definition:** A summation of the number of buildings per unit area of land surface.

(b) **Interpretation Variables:** This MGI element involves: (a) a count of individual buildings, and (b) a measurement of land area. Since this is most likely to be an element of interest in the analysis of urban areas, there are no important environmental deterrents for this procedure. The task may become more difficult and, therefore, more time consuming if the topographic conditions within an urban area are extremely hilly, thus making it difficult to assess area. Scales may be extremely small--up to about 1:80,000.

(c) **Remote Sensor Applications:** Most imaging types of remote sensors can be used for this element; however, vertical aerial photography is undoubtedly the simplest to use at any level of interpretation ability.

411. HEIGHT OF BUILDINGS

(a) **Definition:** A measurement of the maximum height of a building from ground level to rooftop.

(b) **Interpretation Variables:** As in the case of elements 409 and 410, this element is likely to be principally of interest in urban situations where environmental

limitations are virtually non-existent. In rural areas, trees may provide an obscuring cover for low, residential-type buildings.

(c) Remote Sensor Applications: Resolution limitations of the other sensors (radar, IR, etc.) make aerial photography (B1, C1, and D1) the most readily available tool for building-height measurement. It should be noted, however, that parallax in vertical photography may cause obscuration of ground level for buildings located away from the principal point of the photography. Extensive work has been done to relate building height and material to radar reflectivities with some degree of success. A ratio, ranging from 1-10, of the amounts of energy, transmitted and reflected, has been developed for each type of major building material (i.e., sod through steel). The problems associated with discrimination of these energy levels on the radar scope, however, require collateral information before a positive determination of either height or material can be made. The use of various profilers (laser, etc.) may be applicable for specific instances.

412. FUNCTIONS OF BUILDINGS

(a) Definition: A determination of the use, or uses, made of a building classified as follows: residential, industrial, commercial, institutional, recreational, transportational, and storage.

(b) Interpretation Variables: There are no serious environmental problems which can interfere except where buildings may be very densely packed which would obscure exterior wall areas. The experienced interpreter may use other building characteristics, however, such as form and shape and association with other urban or rural features. Scale is the most critical factor for a detailed classification of the type given above and according to TM 30-245 (1967), scales of 1:12,500 are required.

(c) Remote Sensor Applications: The above task is most easily accomplished with aerial photography, although some scanner types of imagery may also be used with a sacrifice in accuracy of interpretation.

413. CONSTRUCTION MATERIALS OF BUILDINGS

(a) Definition: A determination of the composition of exterior walls, roofs, and foundations according to the following classification. weed, thatch, sod, brick, concrete, stone, and metal.

(b) Interpretation Variables: The only environmental factor that might interfere with interpreting construction material of buildings is if the buildings are so closely spaced that their walls cannot be seen; however, a trained interpreter may be able to use

other criteria related to the previous MGI element (412) to determine construction material.

Scale is extremely significant and a large scale must be used—preferably on the order of 1:12,500 or larger (TM 30-245, 1967).

(c) Remote Sensor Applications: Oblique photography would provide the best overall perspective for seeing the total building. Color photography is likely to provide more information than black and white photography.

414. URBAN LAND USE AREA

(a) Definition: A determination of the land area which can be classified as urban (as determined by present classification methods; i.e., U. S. Bureau of Census or other standards).

(b) Interpretation Variables: The interpretation of urban land use is a relatively gross determination which takes into consideration some of the previous MGI elements such as density of buildings and their functions. There appears to be no serious environmental limitations for making such an interpretation except in certain urban fringe areas which may have some complex intermixture of rural-type land uses among urban-type land uses. Generalization may, however, be employed to take care of such areas.

Since this MGI factor is a relatively gross and general feature, scale is of less importance. Image scales smaller than 1:100,000 may even be used; although, the smaller the scale, the greater is the sacrifice of accuracy in placing the urban/rural boundary.

(c) Remote Sensor Applications: High-altitude aerial photography of any type as well as radar or even thermal IR can be used with success. Vertical modes are more useful than oblique modes since an area measurement must be made.

415. URBAN LAND USE FUNCTION

(a) Definition: A determination of the use, or uses, made of tracts of land within built-up urban areas classified as follows: residential, industrial, commercial, institutional, recreation, transportation, and storage.

(b) Interpretation Variables: This MGI factor is closely linked to MGI element 412 (Functions of Buildings) and is, therefore, largely dependent on that interpretation. The same variables apply.

(c) **Remote Sensor Applications:** Same as for MGI element 412 (Functions of Buildings).

416. RURAL LAND USE AREA

(a) **Definition:** A determination of the land area which can be classified as rural (as determined by present classification methods, i.e., U. S. Bureau of the Census or other standards).

(b) **Interpretation Variables:** Same as for MGI element 414 (Urban Land Use Area).

(c) **Remote Sensor Applications:** Same as for MGI element 414 (Urban Land Use Area).

417. RURAL LAND USE FUNCTION

(a) **Definition:** A determination of the use, or uses, made of tracts of rural land classified as follows: cropland, weedland, pasture (and fallow) land, orchards (including citrus groves and vineyard), and rural industry.

(b) **Interpretation Variables:** No significant environmental problems are likely to be encountered in determining land-use function. Scales may be smaller than for urban land-use functions (MGI element 415). Scales as small as 1:60,000 may be used (Lind, A. O., 1970).

(c) **Remote Sensor Applications:** Aerial photography seems to be the most versatile tool for successful interpretation according to the above classification.

418. DAM HEIGHT

(a) **Definition:** A measurement of the height of a water-impounding structure measured from the level of the stream, on the downstream side, to the top of the structure.

(b) **Interpretation Variables:** The principal significant factor is scale which should be large. Scales of about 1:10,000 (TM 30-245, 1967) are likely to provide best results. The procedure involves simple photogrammetric measurements as outlined in the *American Society of Photogrammetry Manual* (1966).

(c) **Remote Sensor Application:** Stereo aerial photography in the vertical mode or oblique mode would probably provide the best results. However, laser profilers

may also be used. Radar has also been used to locate and determine dam height. But in most instances, these dams have been quite large and constructed of concrete and steel. Smaller dams built from other materials would probably not be detected on radar at the present time; hence a "0" has been placed in Table V under this MGI element. No references were found on the actual use of profilers for this purpose.

419. DAM CONSTRUCTION MATERIAL

(a) Definition: A determination of the composition of the impounding structure according to the following classification. concrete, earthfill, wood, and steel.

(b) Interpretation Variables: Same as for MGI element 413 except that environmental factors would not be significant.

(c) Remote Sensor Applications: Same as for MGI element 413 (Construction Materials of Buildings).

420. DAM FUNCTION

(a) Definition: A determination of the use, or uses, made of an impounding structure classified as follows. hydroelectric power, flood control, navigational, water supply, recreational, or combinations of these.

(b) Interpretation Variables: Environmental factors are not likely to be significant for interpretation of dam function. Scale is probably the more important, and, according to TM 30-245, a scale of about 1:12,500 would provide the required data.

(c) Remote Sensor Applications: Conventional aerial photography is likely to be most useful since other information regarding dams is also readily obtained from this group of sensors.

b. References and Bibliography for the 400 Series.

401-1 TM 30-245, 1967, *Image Interpretation Handbook*, Vol. 1, Naval Reconnaissance and Technical Support Center.

402-1 Amer. Soc. Photogrammetry, 1960, *Manual of Photogrammetry*.

402-2 Leuder, D. R. (1959), *Aerial Photographic Interpretation*, McGraw-Hill.

403-1 (402-1)	
403-2	American Society Photogr., 1960, *Manual of Photographic Interpretation.*
403-3	Wilson, John E., 1969, "Sensor Detection Capabilities Study," U. S. Geol. Survey Circ. 616.
403-4	Stoeckelar, E. G., 1968, "Use of Color Aerial Photography for Pavement Evaluation Studies," State of Maine, Materials and Research Technical Paper 68-6R.
403-5	Lind, A. O., 1970, "An Evaluation of Multiband and Color Aerial Photography for Selected MGI in a Subtropical Desert Environment," USAETL, Tech. Rpt. 54-TR.
404-1 (402-1)	
404-2 (403-3)	
405-1 (401-1)	
406-1 (401-1)	
406-2 (402-1)	
407-1 (402-1)	
408	See element 407 for reference.
409-1 (401-1)	
410	No references.

411-1 (401-1)	
411-2	Avery, E., 1968, *Interpretation of Aerial Photographs*, Burgess.
412-1 (401-1)	
412-2	American Soc. Planning Officials, 1951, "Urban Mapping, Aerial Photography and Duplicating: Some Basic Elements," Information Rpt. No. 29.
413-1 (401-1)	
414-1 (412-2)	
414-2	Simpson, Robt. B., 1970, "Recognition of Settlement Patterns Against a Complex Background," Dartmouth College Project in Remote Sensing (Dept. of Geography).
414-3	
414-4	Moore. E. G. and Wellar, B. S., 1969, "Urban Data Collection by Airborne Sensor," *Journal of the Amer. Inst. of Planners*, V. 35.
414-5 (403-2)	
415-1	See element 412 for references.
416	See element 414 for references.
417-1 (403-5)	
417-2	Steiner, D., 1965, "Airphoto Applications for Rural Land Use Studies." *Photogrammetria*, V. 20.
417-3	Steiner. D., 1965, "Use of Air Photographs for Interpreting and Mapping Rural Land Use in the U. S.," *Photogrammetria*, V. 20.

417-4 Beesch, Hans, and Steiner. D., 1959, "Interpretation of Land Utilization from Aerial Photographs," Geographisches Institut der Univ. Zurich.

418-1 (410-1)

418-2 (402-1)

419 No references.

420-1 (401-1)

Table V. Cultural and Industrial-Economic Elements

MILITARY GEOGRAPHIC INFORMATION REMOTE SENSOR MATRIX	UV	PANCHROMATIC				COLOR				COLOR IR				PAN IR.				MULTI-BAND	NARROW BAND	T.V.	MULTI-SCANNER	IR SCANNER	MICROWAVE	RA RADARS	SA RADARS	GAMMA RAY	RADIOMETRIC-SPECTROMETRIC	LASERS	MAGNETOMETRIC	GRAVIMETRIC	SPECIALIZED ELECTROMAG.	PENETROMETER
*	A	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
401 FOOT TRAIL ALIGNMENT	2	C 2	0	2	0	A 2	0	2	0	B 2	0	2	1	2	0	2	0	2	2	1	1	1	1	1	1	X	X	X	X	X	X	X
402 ROAD WIDTH	2	C 2	1	2	1	B 2	1	2	1	A 2	1	2	1	2	1	2	1	2	2	1	1	1	1	0	0	X	X	1	X	X	X	X
403 ROAD SURFACE COMPOSITION	1	1	1	1	1	A 2	2	2	2	B 2	2	2	2	[illegible]	1	2	1	C 1	1	0	0	0	1	1	1	X	X	X	X	X	X	X
404 RAILROAD ALIGNMENT	2	A 2	0	2	0	B 2	0	2	0	C 2	0	2	0	2	0	2	0	2	2	1	1	1	1	1	1	X	X	X	X	X	X	X
405 NUMBER OF RAILROAD TRACKS	2	A 2	2	2	2	B 2	2	2	2	C 2	2	2	2	2	2	2	2	2	2	1	1	2	0	0	0	X	X	1	X	X	X	X
406 BRIDGE LENGTH	2	C 2	1	2	1	A 2	1	2	1	B 2	1	2	1	2	1	2	1	2	2	1	1	1	1	1	1	X	X	1	X	X	X	X
407 BRIDGE CLEAR WIDTH	2	A 2	2	2	2	B 2	2	2	2	C 2	2	2	2	2	2	2	2	2	2	1	1	1	0	0	0	X	X	0	X	X	X	X
408 BRIDGE CLEARANCE	1	A 1	1	1	1	C 1	1	1	1	1	1	1	1	B 1	1	1	1	2	1	1	1	1	1	0	0	X	X	1	X	X	X	X
409 AREA OF BUILDINGS	2	C 2	1	2	1	A 2	1	2	1	B 2	1	2	1	2	1	2	1	2	2	1	1	1	1	0	0	X	X	X	X	X	X	X
410 DENSITY OF BUILDINGS	2	A 2	1	2	1	B 2	1	2	1	C 2	1	2	1	2	1	2	1	2	2	1	1	1	0	1	1	X	X	1	X	X	X	X
411 HEIGHT OF BUILDINGS	1	A 2	1	2	B 1	B 2	1	1	1	C 2	1	1	1	2	1	1	1	1	1	1	1	1	0	0	0	X	X	1	X	X	X	X
412 FUNCTIONS OF BUILDINGS	1	1	A 1	1	1	1	B 1	1	B 1	C 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	X	X	X	X	X	X	X
413 CONSTRUCTION MATERIALS OF BUILDINGS	1	1	1	1	1	C 1	A 1	1	1	1	B 1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	X	X	X	X	X	X	X
414 URBAN LAND USE AREA	2	C 2	1	2	1	A 2	1	2	1	B 2	1	2	1	2	1	2	1	2	2	1	1	1	1	1	1	X	X	X	X	X	X	X
415 URBAN LAND USE FUNCTION	1	C 1	1	1	1	A 1	1	1	1	B 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	X	X	X	X	X	X	X
416 RURAL LAND USE AREA	2	C 2	1	2	1	A 2	1	2	1	B 2	1	2	1	2	1	2	1	2	2	1	1	1	1	1	1	X	X	X	X	X	X	X
417 RURAL LAND USE FUNCTION	1	1	1	1	1	A 1	1	1	1	C 1	1	1	1	1	1	1	1	B 1	1	1	1	1	1	1	1	X	X	X	X	X	X	X
418 DAM HEIGHT	1	A 1	1	1	1	B 1	1	1	1	C 1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	X	X	1	X	X	X	X
419 DAM CONSTRUCTION MATERIAL	1	1	1	1	1	A 2	2	2	2	B 2	2	2	2	1	1	2	1	C 1	1	1	0	0	1	1	1	X	X	X	X	X	X	X
420 DAM FUNCTION	1	1	1	1	1	A 1	1	1	1	B 1	1	1	1	1	1	1	1	C 1	1	1	0	0	1	1	1	X	X	X	X	X	X	X

*For B through E: 1 = vertical; 2 = oblique; 3 = strip; 4 = panoramic.
See Table I for Sensors. Letters over each column correspond to listing in Table I.

III. DISCUSSION

13. General. The matrices presented in Tables II through V represent the results of an initial attempt to evaluate 20 selected remote sensors for their ability to obtain data on specific natural and cultural terrain components (81 selected MGI elements). The evaluations were coded 0, 1, 2, and X according to the following definitions:

0 = failure at both levels of interpreter experience (extensive ground data collection or other supplementary data is required at the present state-of-the-art).

1 = probable success at the professional level only.

2 = probable success at the professional and technician levels.

X = remote sensor—MGI element selection is mutually exclusive or incompatible.

The MGI elements were categorized into four major divisions: (1) Drainage and Water, (2) Vegetation, (3) Landforms and Surficial Materials, and (4) Cultural and Industrial-Economics. The problems associated with detection of each MGI element, recommended interpretation techniques, and the references pertinent to each evaluation are presented.

As may be expected, there were numerous problems associated with a study of this type. Most of these could be solved if the image interpreter, the sensing systems, and the terrain could be calibrated or if all interpreters had the same level of expertise with all types of imagery, the same degree of understanding of the natural sciences, and the same experience with terrain conditions in all areas of the world.

One of the more basic problems was the need to make objective evaluations related to the art of remote sensing—an art which is highly subjective. To be effective, the evaluations had to consider not only the wide range of environmental effects on the terrain that could either hinder or enhance interpretation but also the human factors and the quality variations of each image type. The geologist, for example, knowledgeable with limestone formations developed under tropical conditions, would be able to recognize these or similar formations from R.S.I. in any tropical area. If, however, he were asked to perform the same function in the arctic, he may have difficulty. Limestone in a tropical area has entirely different weathering characteristics from limestone formations found in the arctic. Without the aid of image keys or existing geological maps, the inexperienced interpreter is often forced to make extensive ground surveys before his task can be accomplished. The experience level or the information training

of an interpreter is extremely important and cannot be over-emphasized when evaluating R.S.I. as the above example attempts to illustrate.

The MGI elements, as considered in this study, can be divided into two basic types. The first is the simpler and can usually be obtained directly from the imagery either by simple observation or with basic photogrammetric measurements. Examples of this type would include elements 405 (number of RR tracks) and 409 (area dimensions of buildings). These elements can be usually detected by the technician-level interpreter. The second type is more complex and contains those elements that require a greater degree of experience (professional-level interpretation). Among the elements most difficult to determine from R.S.I. are those dealing with plant species identification (elements 208, 218, 220, 222, and 224). This problem can better be appreciated when it is realized that over 100,000 species of plants are found in the tropics alone and that identification from ground observation is often difficult.

The variability of image quality is also a factor that has to be considered in evaluating R.S.I. for MGI capabilities. In this study, only imagery of the "highest quality" was evaluated. In actual practice, however, the term "quality" is difficult to define because the quality requirements can vary with the interpretation problem, especially with aerial photography. With some MGI elements, 207 (Tree Height) for example, low-contrast, flat imagery is considered to be optimum; while, for element 206 (Area of Clearings), high-contrast imagery provides the best data source.

In the earlier stages of this study, it was anticipated that additional information, sensor development, interpreter training, etc., could be gained by summation of the evaluations.[5] It now appears, however, that bias in selection of the MGI elements and the inequalities in the interpretation difficulties of the MGI elements would make this an unwarranted exercise. As an example, the 100 series category had the highest percentage of code 1 evaluations with the landforms, cultural, and vegetation categories following in descending order. At the lower level of interpreter experience (code 2), vegetation was the highest followed by the cultural elements, landforms, and drainage elements. The high number of code 1 evaluations attained by the drainage category can possibly be explained by either the high degree of complexity associated with detecting the MGI elements in this category or methods for obtaining information on these elements from R.S.I. being not as well known as those used for some of the other elements. Many of the MGI elements were selected with prior knowledge that information was easily obtainable from R.S.I. Many of the vegetation elements were selected in this manner probably accounting for the high value of code 2 evaluations in this category. Before any additional information can be acquired from the matrix, the MGI elements

[5]Interim Report, 1969, "A Matrix Evaluation of Remote Sensor Capabilities for Military Geographic Information."

would have to be relisted according to their complexity and to the availability of the techniques needed for their derivation form R.S.I.

As was stated earlier in this report, the evaluations were based on the experience of the Photographic Interpretation Research Division personnel and the available literature. In many of the articles reviewed, it was difficult to separate pure opinion from actual experience; and, often, the authors did not provide enough information to permit an MGI/sensor evaluation. The literature did not equally cover all aspects of the MGI/sensor field so that for some evaluations there was a surplus of reports while for others, especially those at or near the "state-of-the-art," there was little or no information available. The lack of references available for a given sensor or MGI data element is, in itself, a reflection of the utility, maturity, and availability of the various sensor systems.

IV. CONCLUSIONS

14. Conclusions. It is concluded that:

a. This study subject is transitory, and a constant updating is necessary to keep pace with the rapidly expanding technology in sensor concept, design, and application. Accumulation of new information from tests and other sources is a continuous function. An update of this report will be considered in 2 years. That update will be based on:

(1) Using actual imagery for evaluation rather than the technical literature (the method used in this study).

(2) Employing large groups of interpreters at both the professional and technician level to permit statistical evaluation of remote sensor capabilities.

(3) Formulating a matrix for each major climatic zone rather than one matrix for all climatic zones.

(4) Stratifying MGI elements into groups of equal detection difficulties and common characteristics.

(5) Employing a more concise breakdown of MGI elements. Some elements, such as Ice Type (115), were too general.

(6) Using imagery of known or recognized terrain test areas for evaluation, such as the present USAETL Test Site Program.

b. Research is needed to develop methods and techniques for deriving quantitative terrain information from R.S.I. Evaluation criteria for various forms of R.S.I. must be developed.

c. Research is needed with the state-of-the-art and with classified sensors to develop the methods for collecting terrain information.